AAiT

ADDIS ABABA INSTITUTE TECHNOLOGY
አዲስ አበባ ቴክኖሎጂ ኢንስቲትዩት
ADDIS ABABA UNIVERSITY
አዲስ አበባ ዩኒቨርስቲ

Developing a Decision Support System for Spare Parts Inventory Management to Reduce Repair Cost at Sunshine Construction.

Thesis Final Report:

By: Biruk G/Medhine

A Master’s thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for Degree of Masters of Science in Mechanical and Industrial Engineering (Industrial Engineering Stream)

Advisor: Dr. Ameha Mulugeta
Co-advisor: Mr. Ayele Legesse
Addis Ababa University
Addis Ababa Institute of Technology (AAiT)
School of Mechanical and Industrial Engineering (SMIE)
Industrial Engineering Chair

2024

Acknowledgement

There are many people I would like to thank for helping me through this thesis writing. First of all, I want to thank God. second, to my advisor, Dr. Amha Mulugeta and Ayele Legesse, I would like to express my sincere appreciation for your tireless efforts to help me in the process of writing my thesis.

Also, thank you to everyone who befriended me with ideas and information and helped me become a better student and a better professional. Likewise, you have provided my friends with constant support, loyalty, and most of all, friendship.

Especially to my family and beautiful wife eyerus desalgen, daily words of encouragement; nothing can replace the love, support and encouragement you have given me, thank you very much.

Abstract

The research aims to develop a decision support system (DSS) for spare parts inventory management in order to reduce maintenance costs at Sunshine Construction Company. The study employs a well-designed approach, incorporating data analysis techniques and leveraging DSS systems to gain insights for optimizing inventory management and reducing repair costs.

The literature review examines inventory management in the construction industry, focusing on areas like optimizing stock levels, lead-time, decision support systems, maintenance, and repair cost control. It explores strategies such as (s, S) and (q, r) policies, modern inventory management technologies, and the importance of collaboration among stakeholders. A critical issue identified in the review is the need to address the challenge of inaccurate demand forecasting, which can significantly impact inventory optimization efforts.

The data collection and analysis used both quantitative data from a case company concerned department recording data like inventory levels, repair costs, maintenance costs) and qualitative data (through interviews). Tools like Excel, FMEA, and the EOQ model are used to analyze and optimize factors like stock levels, lead times, reorder quantities, and safety stock.

The expected findings and recommendations aim to improve inventory performance, reduce costs, and promote business success in spare parts management at Sunshine Construction Company. The study aims to contribute innovative solutions related to demand forecasting, inventory policies, maintenance cost control, and technology integration.

Table of Contents

List of Tables:

List Of Figures:

List of Abbreviation

AAiT	Addis Ababa Institute of Technology
ADI	Actual Demand Information
CPFR	Collaboration Planning, Forecasting, And Replenishment
CV	Coefficient Of Variation
DSS	Decision Support System
EDSS	Enterprise decision support system
ECM	Engine Control Module
EOL	End-Of- Life
EOQ	Economic Order Quantity
ERP	Enterprise Resource Planning
ET	Ethiopian Calendar
FBP	Final Buy Problems
FMEA	Failure Mode and Effect Analysis
IECU	Inventory Excess/ Capacity Utilization
JIT	Just-In-Time
LT	Lead Time
MIS	Management Information System
RFID	Radio Frequency Identification
ROP	Reorder Point
RPN	Risk Priority Number
SMIE	School Of Mechanical and Industrial Engineering
SPPRP	Spare Part Requirement Planning
SPSS	Statistical Package for The Social Science
SS	Safety Stock
THC	Total Handling Cost
TIC	Total Increment Cost
TOC	Total Ordering Cost
TPS	Transaction Process System
EDSS	Enterprise decision support system

CHAPTER ONE

1. Introduction

As the construction industry is a direct contributor to a country's economic growth and development, the efficient management of inventory and maintenance parts directly related to the sector is fundamental to the success of construction companies. Effectively managing these critical resources is therefore of paramount importance.

However, many companies, including Sunshine Construction Company, face challenges in effectively managing their equipment maintenance and inventory processes. These challenges, such as high maintenance costs and inefficient spare parts inventory management, can significantly impact profitability and operational efficiency.

Controlling maintenance costs is a critical task for in the construction industry, especially those with extensive equipment usage in heavy construction projects (Manikandan et al., 2018). The aim of reducing maintenance costs is to maintain a balance between the spare part available associated with forecasting reorder Leadtime (Babaveisi et al., 2023). Factors such as regulatory penalties, revenue losses due to equipment unavailability, and broader corporate implications of equipment failures need to be considered. Investing in preventative and predictive maintenance activities aligning with industry best practices is justified for safety-critical equipment, considering the potential costs of accidents or incidents.

Maintenance costs are a significant concern for construction companies, as they constitute a substantial portion of total operating costs and directly affect project duration, cost savings, and overall productivity. The costs of maintenance can vary depending on equipment types, company policies, and operating conditions, making effective forecasting and management a challenging task(Shrestha, 2021).Accurate prediction of equipment maintenance costs enables contractors to plan budgets, allocate maintenance resources, and make informed decisions regarding equipment repair, overhaul, and replacement(Teerasoponpong & Sopadang, 2022).

In addition to maintenance costs, inefficient spare parts inventory management poses another challenge for construction companies(Vicil, 2021). Inventory control is crucial for the success and supply chain performance of organizations(Jonsson & Mattsson, 2019).Inadequate inventory management can result in increased costs such as capital tied up in inventory, storage expenses, loss of revenue, and operational inefficiencies. Furthermore, ineffective inventory control systems can lead to difficulties in timely procurement, poor lead time forecasting, and lack of transparency in information accessibility(MSHIU, 2021).

Efficient inventory management is essential for the operational success and overall performance of construction companies(Atnafu & Balda, 2018). It involves effectively maintaining and controlling production levels to meet organizational needs. The characteristics of demand, such as uncertainty and structural dependence, play a significant role in determining the appropriate inventory management approaches(Boute et al., 2022).

However, striking the right balance between maintaining adequate spare parts inventory and cost considerations can be challenging(Hu et al., 2018). Holding excessive inventory leads to capital waste, while insufficient inventory results in maintenance delays and project interruption (Ramos et al., 2020). Effective spare parts management requires the use of forecasting techniques, implementing equipment management policies, and considering the financial implications of spare parts availability in the event of equipment failure.

To overcome those challenges in the construction industry, research is needed to identify problems and provide effective solutions to improve equipment maintenance costs and inventory management. This proposal aims to considering a scientific approach, which includes survey methodology, data collection from relevant internal and external stakeholders, and quantitative and qualitative data analysis. The research objectives are to identify challenges associated with equipment maintenance cost and spare parts inventory management and provide strategies and recommendations to optimize these areas. The expected outcomes of this research are practical insights and recommendations that construction companies can implement to improve spare parts inventory management, and reduce repair costs.

1.1. Background and justification

Inventory management are focused on addressing key problems such as uncertainties in demand and supply, ordering decisions, and inventory ranking. They aim to develop strategies, models, and decision support systems (DSS) to manage uncertainties and achieve optimal inventory replenishment(Jamaludin & Bahaudin, 2022). Various researchers in this field have tried to put tools and methods in their studies to help companies make informed ordering decisions and improve inventory management practices. The focus is on optimizing order quantities, reordering points, and inventory maintenance decisions to reduce costs(Hu et al., 2018; Ramos et al., 2020), improve efficiency(Manikandan et al., 2018), improve inventory control, and ultimately contribute to companies' profitability. Additionally, inventory ranking systems have been suggested to prioritize items based on quantitative and qualitative factors, ensuring that resources are allocated to the most critical items. Their overall goal is to provide innovative solutions that enhance operational performance and drive business success(Manikandan et al., 2018).

Sunshine Construction Company, like many others in the industry, faces critical issues related to inventory management and equipment maintenance. The organization struggles the causes of low stock levels, lead time, the consequences for maintenance cost, and inadequate spare parts management. These challenges result in unnecessary expenses, increased downtime, and hindered operational efficiency. The lack of necessary spare parts in the warehouse has a direct impact on equipment maintenance, leading to extended maintenance activities and potential consequences if critical components are not readily available.

The 2015 ET Company Annual Report highlights on table-1 that 50.11 % of total equipment downtime was attributed to the unavailability of spare parts in the required quantity and time(Department, 2015). This indicates that stockouts significantly impact the company's operations and contribute to negative result. For this result now a day in the main workshop where equipment and vehicles are repaired and maintained, more than 30 different equipment have been out of service for more than six months due to lack of required spare parts. This extended downtime greatly affects the company's ability to complete projects on time.

Table 1: 2015ET Company Annual Report for Equipment Total Down Hour And Reason

No	Equipment Type	Total Down	Service	Under Repair	Spare Part Not Available	Waiting Other Equipment	Waiting Transport	Waiting Man Power	Waiting External Work Shop Activity	Tire	Accident
1	Dozer	842.3	15	152.3	409	156	61	20	29	0	0
2	Loader	256.4	0	75.1	103	0	50	15	0	13.3	0
3	Excavator	638.5	8	138	224.5	0	75	12	181	0	0
4	Grader	683.3	0	82	421.3	88	28	25	0	39	0
5	back-loader	333	8	54	238	0	33	0	0	0	0
6	Sandvik drill machine	315	8	20	150	0	45	0	81	11	0
7	Dump Trucks	1,911.90	0	351.8	988	0	0	0	192	156.1	224
8	small vehicles	393	0	72	159	0	0	0	162	0	0
	Total	5,373.40	39	945.20	2,692.80	244	292	72	645	219.4	224
	Down Percentage		0.73%	17.59%	50.11%	4.54%	5.43%	1.34%	12.00%	4.08%	4.17%

The existing literature and practices in construction equipment maintenance and inventory management have not adequately addressed the specific challenges faced by Sunshine Construction Company. Therefore, there is a need for research to fill this gap and provide strategies to optimize equipment maintenance and inventory management.

This research paper aims to study the current practices and challenges at Sunshine Construction Company and propose strategies for optimizing equipment maintenance and inventory management. The research will focus on reducing costs, improving efficiency, and enhancing inventory control to overcome the identified issues. By developing a decision support system for spare parts inventory management, the organization can achieve efficient inventory management minimize downtime, and improve overall operational performance. The findings and recommendations of this research will contribute to the existing knowledge in the field and provide valuable insights for future work in construction equipment maintenance and inventory management.

1.2. Justification

The research done by Sunshine Construction Company to develop a Decision Support System (DSS) for spare parts management is well justified by several key factors.

First, the company faced significant challenges in managing spare parts including low stock levels, long lead times, high maintenance costs and inadequate spare parts management, resulting in increased grass downtime, unnecessary costs and operational inefficiencies. .

Secondly, the literature and practices in construction equipment maintenance and inventory management do not provide sufficient information to adequately address the unique challenges faced by Sunshine Construction Company, this study fills the gap by providing a comprehensive framework to facilitate equipment maintenance and inventory management;

The study also aims to develop strategies, models and a decision support system (DSS) to manage uncertainties and optimize inventory to reduce unnecessary costs, improve efficiency and improve inventory control, including optimization of order quantities, reorder points and inventory maintenance decisions.

In addition, the study will help the company to focus on the most important parts and improve the overall operational performance by implementing an inventory ranking system to prioritize spare parts based on quantity and quality factors.

By developing a comprehensive DSS for spare parts inventory management, the study aims to provide innovative solutions that enhance company performance and promote business success. This includes reducing downtime, reducing maintenance costs and improving overall efficiency.

Finally, the conclusion and recommendations of this research will contribute to the improvement for in the case company equipment maintenance and inventory management, providing valuable insights for future work in this field.

1.3. Problem Statement

Sunshine Construction is one of the indigenous contractors engaged in the construction sector in the country and is contributing to the development of the country. Currently, the company has three active road construction projects, namely Degolo-Kellala Project, Debrebirhan-Ankober Project, and Debrebirhan. -The Jihur project is under implementation. Apart from rental equipment, the company has deployed more than 150 earth-moving machines and 250 light and heavy vehicles as well as other construction machines/auxiliary machines for these ongoing road construction projects.

The Sunshine Construction Company, operating in the construction sector, is currently experiencing critical issues in inventory management that have a significant impact on its profitability. a case company inadequate inventory management practices have resulted in low stock levels, increased downtime, reduced operational efficiency, and high maintenance costs. The main causes of these challenges include insufficient stock reviews, ineffective stock management practices, inaccurate demand forecasting, and inconsistent supply chain processes. Inadequate spare parts management at Sunshine Construction Company has resulted in extended equipment downtime, leading to project delays and disruption of company operations. The company's inability to meet its current needs despite having a substantial stock of spare parts indicates shortcomings in its spare parts management practices.

Based on the information provided in Table-1 of the 2015 ET Company Annual Report, it is evident that 50.11 % of the total equipment downtime is directly attributed to the unavailability of spare parts in the required quantity and within the specified time frame(Department, 2015).This data strongly suggests that the stock levels of spare parts have a substantial impact on the company's operations and are leading to negative outcomes.

Currently, more than 30 different types of equipment in the main workshop available for equipment repair and maintenance have been non-operational for a period exceeding six months(Department, 2015). This prolonged downtime is primarily attributed to the unavailability of the required spare parts. This extended downtime severely hinders the company's ability to complete projects on time and significantly affects overall operational efficiency.

While the 2015 annual inventory report states that the company has a spare parts inventory valued at 114.9 million birr(Department, 2015). it is important to recognize that simply having a substantial stock of spare parts does not guarantee that the organization's current needs are being adequately met.

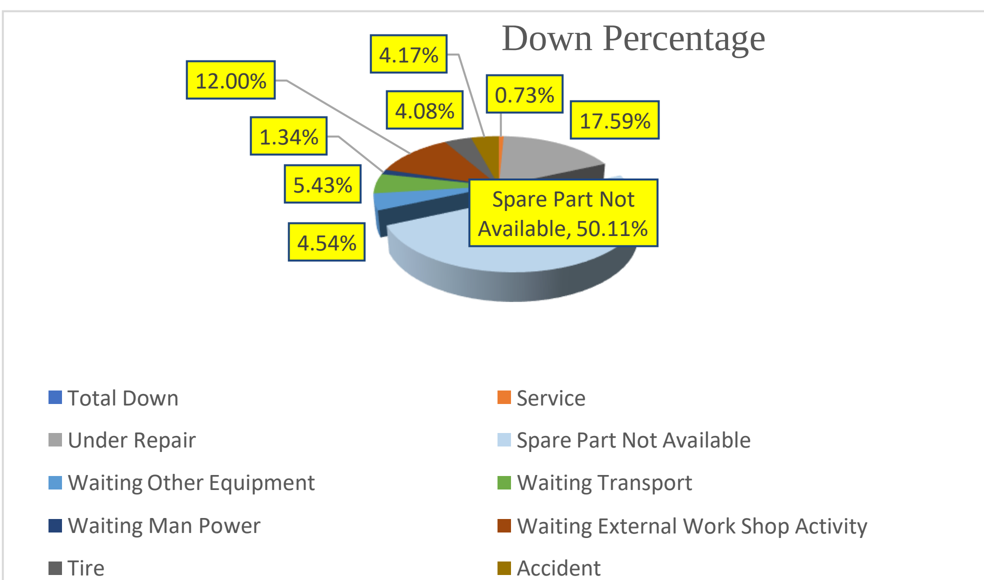


Figure 1: Equipment Down Percentages

To overcome these challenges, it is crucial for the company to develop a suitable inventory management strategy. This strategy should involve accurate determination of inventory levels and lead time, as well as the implementation of modern inventory management technologies such as barcode systems or real-time inventory control. Adhering to process control and inventory management practice standards is vital, and techniques like economic order quantity (EOQ) can assist in optimizing order quantities.

To enhance inventory management practices, it is essential for the company to focus on accuracy of demand forecasting through data analysis is crucial to anticipate and meet inventory needs effectively. By analyzing historical data for spare part need pattern, the company can make more informed decisions about inventory levels and replenishment, and evaluating the coordination and communication among internal departments involved in the company's supply chain processes is vital. Effective collaboration and information sharing between departments such as procurement, can streamline inventory management. This includes regular meetings, sharing forecasts and spare part need data, and implementing efficient communication channels to ensure timely and accurate information flow.

By addressing these research gaps and implementing the recommended solutions, Sunshine Construction Company can improve its inventory management, meet spare parts demand, embrace technology adoption, and enhance overall performance and profitability.

The challenges in equipment maintenance and inventory management are not unique to Sunshine Construction Company but are prevalent in the construction industry. Various industries, including construction, face similar equipment management challenges such as time-consuming and error- prone manual processes, equipment tracking, and irregular maintenance expenses. The implementation of modern technologies such as barcode can significantly improve equipment management and maintenance practices, leading to enhanced efficiency, reduced downtime, and optimized costs.

In conclusion, Sunshine Construction Company must address its inventory management challenges by implementing modern technologies, improving demand forecasting accuracy, and optimizing inventory control strategies to enhance overall performance and profitability.

Research Question

1. How can the organization optimize stock levels and improve lead time for spare part inventory managements?

2. How can improve coordination and communication among internal departments to streamline spare parts inventory management and ensure timely and accurate information flow?
3. How can organization develop a decision support system to effectively manage spare parts inventory and minimize repair costs.

1.4. Objective of the Study

1.4.1. General Objective

To improve the maintenance and inventory management of construction equipment in the case company to reduce repair costs, and enhance spare parts management.

1.4.2. Specific Objective

To optimize stock levels and improve lead time for spare part inventory managements.
To improve coordination and communication among internal departments to streamline spare parts inventory management and ensure timely and accurate information flow.
To develop a decision support system for optimize spare part inventory management and minimize repair cost.

1.5. Significant of The Study

Addressing Sunshine Construction's inventory management issues is critical for several reasons, including improving operational efficiency by reducing poor inventory management techniques, reducing downtime, reducing maintenance costs, inventory, and warehouse inventory, all of which protect the organization from unnecessary costs by ensuring proper inventory control; Putting effective inventory management systems in place can improve the company's overall performance and inventory management. Other organizations with related problems can use it as a guide. Ultimately, better inventory management techniques reduce financial risks, increase resource utilization, and increase operational resilience, helping the organization remain viable over the long term.

1.6. Scope and Limitation of The Study

1.6.1. Scope

The scope of this study is focused on the inventory management practices and maintenance costs at Sunshine Construction, specifically within the main warehouse of Galan Terminal. The study includes an analysis of the current inventory management practices, identification of challenges related to spare parts management, and research on effective solutions and best practices in areas such as inventory control, lead time forecasting, and software utilization. The study aims to develop customized strategies and recommendations based on the specific needs and context of Sunshine Construction. The implementation of the recommended solutions will be monitored to assess their effectiveness. However, it's important to note that this study does not cover the root causes of equipment failure or software development. The findings and recommendations are specific to the study period and the scope of Sunshine Construction's operations at the Galan Terminal main warehouse.

1.6.2. Ethical consideration

A study of Sunshine Construction Company's development of a decision support system (DSS) for its supply chain operations raises several key ethical issues. First, before collecting or requesting any data, the relevant stakeholder must ensure data privacy and security by implementing strict protocols, explaining that the data will only be used for research purpose.

Regarding algorithm transparency and fairness, the study should provide clear explanations of the data, algorithms, and decision-making models used in DSS. The algorithms should be carefully analyzed to ensure they do not lead to unfairness or personal harm, and feedback mechanisms should be developed to allow stakeholders to understand and challenge DSS recommendations.

Business sustainability is another important issue. DSS should incorporate sustainability factors such as stock level and reducing costs in the Sunshine Construction supply chain. Aligning DSS with circular economy principles can further enhance its impact in the business process and should provide insights and recommendations to improve the overall sustainability of DSS implementation.

The study should examine the impact of DSS on jobs, work roles and working conditions in the supply chain by examining worker safety and work impact. Any negative impact on the company and potential risks of the DSS implementation process should be carefully evaluated.

Finally ,the organization actively engages with various departments to understand their needs and concerns and incorporate their input to adapt the DSS to their needs and minimize negative impacts on the organization. The study should demonstrate how DSS can contribute to wider company benefits such as increasing stock levels and the company's profit development opportunities.

1.6.3. Limitation of the study

Limitations of Generalizability: The focus of the study on one case company ,does not allow to ensure that the proposed solutions are effectively implemented in different organizational situations, as it depends on the willingness of the participants to generalize the findings and their applicability to other construction companies or industries.

Scope Limitation: The study does not cover the root causes of equipment failure or software development, but instead focuses specifically on spare parts inventory management practices. This limited scope may not identify all relevant factors or relationships that affect spare parts inventory management.

Disciplinary Limitations: The study is limited to a specific discipline or field, which may limit the breadth and depth of understanding by not integrating disciplinary perspectives. Challenging established knowledge and assumptions in different fields can lead to more valuable contributions.

Big data :The analysis of inventory and maintenance data is hindered by the challenges of very big data. The vast scale and complexity of the data pose significant limitations to systematic and comprehensive examinations. One key issue is the limited demonstrated approaches for dealing with large, multidimensional data sets. Traditional analytical methods may prove inadequate to fully capture the nuances and interdependencies in the data.

. Organizational Limitations: Adapting these solutions to other organizations may require further validation and customization as the proposed conceptual model and decision support system are tailored to the specific needs and context of Sunshine Construction Company. By addressing these limitations, the research can increase understanding of spare parts inventory management practices and their impact on maintenance costs, leading to more valuable contributions to the field.

CHAPTER TWO

2. Literature Review

Inventory management in the construction industry involves the systematic control, procurement, storage, and distribution of spare parts required for equipment maintenance and repair. It ensures the availability of critical components, reduces equipment downtime, enhances operational reliability, and ensures smooth project execution(Yusuf & Soediantono, 2022). Effective spare parts inventory management is essential for construction companies as it improves equipment performance, reduces maintenance costs and increases overall productivity(Kulshrestha et al., 2024).

Construction companies encounter several challenges when managing spare parts inventory. These challenges include the variability of equipment and machinery, limited storage space, unpredictable demand patterns, and the risk of obsolescence. Balancing inventory levels to avoid stockouts while minimizing carrying costs is a significant challenge. Inaccurate demand forecasting, inadequate visibility into inventory levels, and inefficient inventory control systems further complicate spare parts management(Zhang et al., 2021). Developing a decision support system (DSS) for spare parts inventory management can address the challenges mentioned above and improve overall efficiency(Tahir & Choudhary, 2011). A decision support system (DSS) in the construction industry for managing spare parts inventory improves various aspects, including demand forecasting, inventory control optimization, tracking and visibility enhancement, procurement and ordering streamlining and enabling data- driven decision-making(Ma et al., 2020).

2.1. Spare Parts Inventory Management in the Case of the Construction Industry

Efficient spare parts inventory management is crucial in the construction industry as it directly affects multiple aspects of operations and project performance (Atnafu & Balda. Implementing effective inventory management practices allows construction companies to optimize their spare parts inventory, ensuring the availability of necessary parts while minimizing carrying costs and the risk of obsolescence or spoilage(Alahmadi & Jamjoom, 2022). This leads to maintaining optimum inventory levels and implementing effective tracking and procurement systems, construction companies can minimize equipment downtime and maximize project efficiency(Nchekwube et al., 2022), improved equipment optimizing inventory levels through proper management, construction companies can mitigate these risks and reduce repair costs in the long term(Siponen et al., 2019). This involves accurately forecasting demand, setting appropriate reorder points and quantities, and regularly monitoring inventory levels. By ensuring the availability of necessary spare parts without excessive stock, construction companies can minimize repair costs and improve overall cost-efficiency. performance, enhanced project efficiency, and overall cost savings. By maintaining the right balance of inventory levels, utilizing advanced tracking and procurement systems, and adopting data-driven decision-making, construction companies can achieve efficient spare parts inventory management and maximize their operational effectiveness.

2.1.1. Challenge of Inventory Management

Effective inventory management is vital in spare parts management across industries such as manufacturing, automotive services, and equipment maintenance. the challenge of accurately predicting the demand for spare parts on construction industry, which can be impacted by equipment breakdowns, maintenance schedules, and unforeseen repairs(Pawar & Tiple, 2019).The objective is to maintain optimal inventory levels that fulfill demand while minimizing costs(Jonsson & Mattsson, 2019). Key challenges in spare parts management on construction industries include accurately predicting demand to ensure the availability of the right spare parts when needed(Boute, 2018). This involves considering factors such as equipment lifecycle, historical usage patterns, and maintenance schedules. Spare parts often come in different models, sizes, or versions, and companies must effectively categorize and track these items to ensure accurate inventory management (Hu et al., 2018).

To address these challenges, companies employ various strategies. They use inventory optimization models that consider factors such as historical usage patterns, lead times, and criticality of parts. These models help determine optimal order quantities, reorder points, and safety stock levels for each spare part.

Effective collaboration with different departments, and service providers is crucial. Sharing information on maintenance schedules, failure rates, and lead times improves forecasting accuracy and enables timely replenishment. Implementing real-time monitoring systems and leveraging data analytics can provide insights into usage patterns, identify potential stockouts or excess inventory situations, and support proactive inventory management decisions(Tiwari, 2021).

Efficient spare parts management leads to benefits such as minimized equipment downtime, improved service levels, and reduced costs associated with inventory carrying and expedited deliveries. It also optimizes resource utilization and enhances overall operational efficiency.

How To Improved Challenges of Inventory Management

The objective is to minimize costs associated with inventory by employing tactics like decreasing inventory levels, enhancing inventory management systems, aligning demand with available capacity, and leveraging market fluctuations to the organization's advantage.

To overcome inventory management challenges in the construction industry, system structure improvement with the integration of technology is crucial(Mazikana, 2023). They suggest utilizing a newsvendor model, a mathematical approach that optimizes inventory by maximizing requirement projections while considering the balance between inventory at the end and the costs of stockouts(Gonçalves et al., 2020).

The use technology has also gained traction in the construction industry, enabling real-time sharing of information about inventory and performance. the advancements in tracking and monitoring inventory through computer and technological advancements facilitate easy data analysis and will shape supply chain operations in the future(Mohsen, 2023).the four strategies for optimizing supply chain operations and gaining a competitive advantage within the construction industry(Khan et al.).

Hedge strategies: Construction companies can design their supply chain operations to offset losses in one area with gains in another, thereby reducing the risk of future losses.

Collaboration and outsourcing: Effective communication regarding inventory uncertainty is promoted, and supporting activities can be outsourced when internal solutions are not feasible.

Flexible strategies: Contingency plans, such as engaging additional suppliers, utilizing multiple construction sites, implementing flexible operations, and maintaining buffer stock, provide supply chain flexibility for effective cost and resource management.

What-if scenarios: Multiple strategies are compared and contrasted to select the most suitable one without compromising customer service and supply chain operations.

2.1.2. Demand management

Demand management involves accurately forecasting and managing customer demand to inform operational decisions. In inventory management, demand can be classified into independent and dependent demand.

Independent demand refers to the specific demand for spare parts based on external factors such as equipment breakdowns or maintenance requirements. On the other hand, dependent demand is determined by the demand for equipment that requires those accessories. The replacement requirement is directly related to the need for supporting equipment.

Different approaches can be applied based on dependent and independent demand to effectively manage spare parts inventory and adapt it to demand. For dependent demand, such as Spare Parts Requirements Planning (SPPRP) or Just-in-Time (JIT) inventory management can be applied for improvement. The right approach to finding the right spare parts is available at the right time to support the maintenance process.

For independent demand, strategies such as forecasting techniques, safety stock management, or demand-based replenishment can be used. These strategies aim to meet customer demand and reduce stockouts by accurately forecasting demand and maintaining appropriate inventory levels.

Commodity demand is often characterized by high volatility and sporadic patterns, making inventory control challenging. Companies typically have a combination of predictable demand and unpredictable demand segments. This, along with factors such as criticality and high cost, requires a high safety margin to account for unexpected demand.

$$ADI = \sum_{t=1}^{n} \frac{t_i}{n} \quad (1)$$

$$y_\alpha = \sum_{t=1}^{n} \frac{y_i}{n} \quad (2)$$

In both equations, where:

t = time

n = number of periods

ya = Average demand

yi=Actual demand(Yavuz, 2023)

Based on the results of ADI and CV, suggested four different demand patterns for spare partdemand.

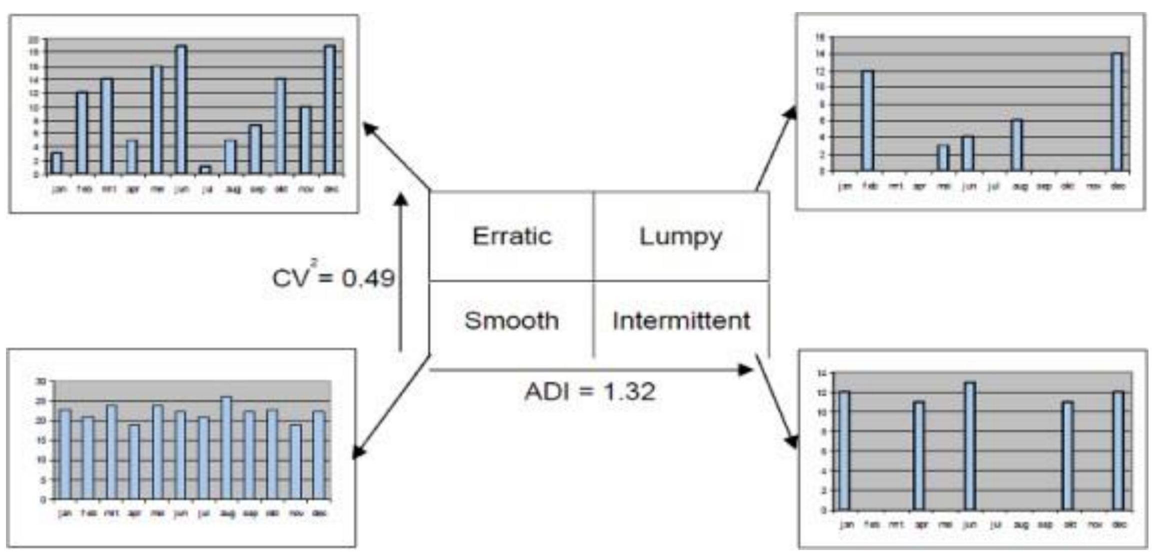


Figure 2:Demand Pattern for Spare Parts source:[(Ali & Ratnayake, 2023)]

According demand patterns for the parts can be described as(Costantino et al., 2018):

Erratic: Demand that is highly variable in size.

Lumpy: Demand that has time periods with no demand at all, but when demand occurs, it is still highly variable.

Smooth: Demand that occurs randomly, with less periods with no demand, and the variability of demand size is modest.

Intermittent: Demand that occurs randomly, with many periods of no demand at all.

In summary, effective inventory management involves dividing demand into independent and dependent demand and applying appropriate inventory management strategies to each. Thus, any companies can ensure the availability of spare parts when needed and improve their inventory levels.

Stock-Out

Different situations occur when stock products occur, depending on the distribution inventory and Inventory shortages, particularly in the case of spare parts or equipment maintenance activity, can have significant consequences. These include disruptions in operations, extended periods of downtime, and increased costs. therefore, reducing maintenance inventory is essential to prevent operational delays and costly downtime in maintenance and spare parts management.

On the other hand, when distribution accumulation occurs, the impact on the organization is usually not significant. Organizations can tolerate short-term unavailability of certain spare parts as minor problems. As a result, suppliers such as wholesalers and retailers may be more tolerant of distribution inventory because wholesalers may not significantly impact customer satisfaction or overall inventory availability.

When a supplier faces insufficient inventory and is unable to meet the customer's demand for spare parts, four possible outcomes may occur:

The customer may not be willing to wait for new stock to become available and seeks alternative solutions or suppliers to fulfill their needs. The customer may choose to switch to another supplier who can provide the required spare parts promptly The unavailability of necessary spare parts may lead the consumer to choose not to proceed with the purchase, ultimately resulting in a lost sale. Unfulfilled demand in maintenance and spare parts management can potentially result in the permanent loss of the customer's business. These outcomes highlight the potential consequences of stock-outs in maintenance and spare parts management, emphasizing the importance of maintaining adequate inventory levels to meet customer needs and avoid disruptions in operations.

In conclusion, the stock results have different implications depending on the distribution or maintenance stocks, especially the maintenance and spare parts management situation. The weight of the impact on the supplier and the customer is different, which leads to different perspectives on stock withdrawal. Minimizing maintenance inventory is critical to preventing disruptions to operations, while distribution inventory can be more tolerable for customers and suppliers. The consequences of out-of-stocks on replenishment can range from waiting for replenishment to lost sales and even losing customers, the impact on the overall bottom line ranging from best to worst.

Safety Stock

Safety stock is a crucial of inventory management that acts as a buffer to mitigate fluctuations in demand or supply. Its primary purpose is to address uncertainties stemming from factors like unpredictable demand patterns, delays in lead time, or inadequate delivery. By including an optimal amount of safety stock in the calculations of the reordering system, companies can maintain an adequate inventory level that guards against stock-outs during regular operations.

The main objective of safety stock is to protect customer service from disruptions. When actual acustomer orders surpass the predicted demand, having sufficient safety stock becomes vital to fulfill those orders and prevent potential customer service problems.

Determining the optimal quantity of safety stock requires careful consideration of various factors. Recent history-data demand patterns, lead time, and the desired service level are among the key parameters that need to be taken into account. Striking the right balance between service level and inventory investment is crucial to ensure that the safety stock quantity is neither too excessive, tying up valuable resources, nor too inadequate, leaving the company vulnerable to stock-outs.

$$SS = Z * \sigma * \sqrt{(T + T * L)} \quad (3)$$

$$T_{SL} = D * (T + TL) + (Z_{\alpha} * \sigma * \sqrt{(T + TL)} \quad (4)$$

$$\text{Order quantity} = \text{target stock level} - \text{stock on hand} - \text{stock onorder} \quad (5)$$

where Z is the inverse number of the normal distribution according to the service level ⟨, T is stock checking period, LT is lead time, D is average demand, and target stock level (TSL)is maximum stock(Ermawanto & Kurniati, 2021).

In conclusion safety stock plays a vital role in inventory management by acting as a buffer against demand and supply uncertainties. Its purpose is to prevent stock-outs and maintain customer service levels. By carefully evaluating demand patterns, lead time, and desired service levels, companies can determine the appropriate quantity of safety stock needed to effectively manage their inventory and fulfill customer orders in a timely manner.

Inventory policy

Inventory policies play a crucial role in managing spare parts inventory throughout a product's life cycle. Different policies are implemented based on the specific phase, including continuous review and periodic review policies in the initial and maturity phases, and final order policies in the end- of-life (EOL) phase.

Inventory policies are essential for managing spare parts inventory throughout a product's life cycle. There are different types of continuous review and periodic review policies commonly used:

A. Continuous Review Policies Are The (S, S) Policy and the (Q, R) Policy.

(s, S) policy: Under the (s, S) policy, the inventory level is continuously monitored, and when it falls below a specified reorder point (s), a new order is placed to replenish the inventory. The order quantity is determined by the difference between the target order-up-to level (S) and the current inventory level. This policy ensures that the inventory is maintained within a certain range to meet anticipated demand and minimize the risk of stockouts. The (S-1, S) policy is a variant of the (s, S) policy commonly used for repairable spare parts, where one unit is ordered for each unit used, reflecting the repair process (q, r) policy: The (q, r) policy is another type of continuous review policy used for spare parts inventory management. In this policy, a fixed order size (q) is placed when the inventory level reaches or falls below a predefined reorder point (r). This ensures that a predetermined quantity is ordered whenever the inventory level drops to a certain threshold. The (q, r) policy helps maintain a consistent inventory level and simplifies the ordering process by using a fixed order size(Ermawanto & Kurniati, 2021).

B. Periodic Review Policy:

(R, S) policy: The spare parts inventory level is monitored periodically in cycles. At the start of each fixed ordering cycle (R), orders are placed to bring the inventory level up to an order-up-to level (S). The length of the ordering cycle is predetermined by decision makers.

C. Final Order Policy:

When the availability of spare parts is discontinued, a final order is placed to fulfill the demand during the end-of-life (EOL) phase. This is known as the EOL inventory problem or final buy problem (FBP) in the maintenance context. Determining the appropriate quantity for the final order is crucial to balance obsolescence and disposal risks and avoid supply shortages that could result in penalties or damage to customer satisfaction or the brand image.

$$\text{Reorder point} = (\text{Average daily demand} * \text{lead time}) + \text{safety stock}$$
(6)

2.2. Optimization of Stock Levels and Lead Time in Spare Parts Inventory Management

Optimizing stock levels and lead time in spare parts inventory management is crucial for efficient operations. Various factors, including production dependence, and delay time, influence stock levels and lead time (Ramezani & Hoseinzadeh, 2022). Researchers have proposed different models and methods for inventory optimization, such as parameterized inventory policies and neural network-based algorithm. To achieve optimal stock levels and lead time, it is recommended to consider the ambiguity faced by risk-neutral managers. These managers tend to become more conservative in choosing stock levels and safety stock when there is uncertainty in lead time(Kim et al., 2022). Mathematical optimization, least squares, and regression analysis can be utilized to determine optimal supply sizes and minimize the cost of inventory management(Perez et al., 2021). Implementing a comprehensive framework like the MRO-MMM framework can be beneficial in optimizing spare parts management. It covers strategies, data management, inventory system optimization, supplier management, and continuous improvement(Ramezani & Hoseinzadeh, 2022). A general formula for using optimization solvers, such as linear programming or integer programming, to find the optimal order quantities that minimize costs while meeting demand requirements:

Objective Function: Minimize:

$$O_q = \sum(C_i * x_i) + \sum(h_i * {}^{D_i}/_{x_i}) \quad (7)$$

Subject to the constraints: $xi \geq Di$ for all i (to meet the demand requirements)

Additional constraints: $xi \geq 0$ for all i (non-negativity constraint) xi is an integer (for integer programming, if applicable)

In this formulation:

xi represents the decision variable for the order quantity of spare part i , Ci represents the ordering cost per unit for spare part i hi represents the holding cost per unit per year for spare part i. Di represents the annual demand for spare part i. di represents the minimum demand requirement for spare part i. The objective function consists of two parts:

The sum of the ordering costs= ($\sum$ (ci * xi)) represents the cost of placing orders for each spare part. The sum of the holding costs= ($\sum$ (hi * (Di / xi))) represents the cost of holding inventory for each spare part, accounting for the annual demand and the order quantity.

The constraints ensure that the order quantity for each spare part is equal to or greater than the minimum demand requirement to meet the demand requirements.

Additional constraints, if applicable, may include constraints on maximum order quantities, capacity constraints, or other specific requirements of the inventory management system.

By solving this optimization problem using appropriate solvers, you can find the optimal order quantities that minimize costs while meeting the demand requirements. The solution provides insights into efficient inventory management decisions, such as order quantities, reorder points, and safety stock levels.

2.3. Decision Support Systems (DSS) in Inventory Management

Researchers in inventory management are focused on addressing key problems such as uncertainties in demand and supply, ordering decisions, and inventory ranking. They aim to develop strategies, models, and decision support systems (DSS) to manage uncertainties and achieve optimal inventory replenishment (Alahmadi & Jamjoom, 2022). Various researchers in this field have tried to put tools and methods in their studies to help companies make informed ordering decisions and improve inventory management practices. The focus is on optimizing order quantities, reordering points, and inventory maintenance decisions to reduce costs, improve efficiency, improve inventory control, and ultimately contribute to companies' profitability(Rubel, 2021). Additionally, inventory ranking systems have been suggested to prioritize items based on quantitative and qualitative factors, ensuring that resources are allocated to the most critical items(Antosz & Ratnayake, 2019). Their overall goal is to provide innovative solutions that enhance operational performance and drive business success.

Accurate demand forecasting is critical to determining optimal inventory levels(Chawla & Miceli, 2019). By analyzing historical data, market trends and spare parts demand, the organization can make informed decisions about inventory replenishment and avoid excess spare parts inventory. Decision support systems help analyze and forecast demand patterns, allowing for more accurate equipment management decisions (Vicil, 2021).

To address these challenges proactively, it is crucial to employ effective inventory control optimization techniques, such as the Reorder Point (ROP) approach(Ali & Ratnayake, 2023). The primary objective is to efficiently manage the inventory of spare parts and minimize the risk of stock shortages. However, it is common for safety stock levels and replenishment schedules to be overlooked, which can result in delays in delivering goods(Efrilianda & Isnanto, 2018). Implementing inventory control procedures in the central warehouse is vital to maintain a well-balanced inventory of spare parts. By utilizing a safety stock approach, optimal minimum and maximum stock levels can be determined, leading to reduced overall supply chain cost (Kim et al., 2022). The Reorder Point (ROP) plays a critical role in determining the ideal timing for restocking spare parts, ensuring timely availability when maintenance is required.

Implementing the economic order quantity (EOQ) model in inventory management offers numerous advantages. It helps reduce inventory and maintenance costs as well as shipping expenses by determining the optimal order size. EOQ also minimizes ordering costs by optimizing the frequency and processing of orders(Gallego-García et al., 2021). The model enhances stock control accuracy, allowing for timely identification of shortages or surpluses. It facilitates improved supplier negotiations by providing economic-based order quantity information. Additionally, EOQ improves company satisfaction by ensuring product availability and reducing backorders. To calculate EOQ, you gather data on demand, unit cost, ordering cost, and holding cost, and apply the formula.

$$EOQ = \sqrt{\frac{2*Demand*order\ cost}{holding\ cost\ per\ unit}} \quad (8)$$

$$EOQ = \sqrt{\frac{2D*S}{H}} \quad (9)$$

Since, the order spare parts are different items the average unit cost (i) must be need to analysis holding cost.

$$Average\ cost\ (i) = \frac{\sum each\ unit\ cost}{number\ of\ items} \quad (10)$$

$$Holding\ cost\ per\ unit C_c = Average\ unit\ cost * percentage\ carrying cost \quad (11)$$

$$Annual\ holding\ cost (H_E) = \frac{Q}{2} * C_c \quad (12)$$

$$Annual\ setup\ cost (C_E) = \frac{D}{Q} * C_O \quad (13)$$

$$Average\ inventory\ (I) = \frac{Q}{2} \quad (14)$$

$$Expected\ number\ of\ order (N) = \frac{D}{Q} \quad (15)$$

$$Inventory\ turns = \frac{annual\ demand}{average\ inventory} \quad (16$$

$$Reorder\ point (R_{OP}) = demandperday(d) * lead\ time\ new\ order(L) \quad (17)$$

$$Demand\ per\ day(d) = \frac{demand}{number\ of\ working\ day} \quad (18)$$

$$R_{OP} = d * L \quad (19)$$

Therefore, total existing annual inventory cost=annual holding cost + annual set up cost

$$TIC = H_E + S_E \quad (20)$$

Identify the costs associated with placing an order, including activities such as order processing, transportation, and paperwork. These costs may include fixed costs (e.g., setup costs) and variable costs (e.g., transportation costs per order).

Evaluate the costs of holding inventory, which include expenses such as storage, insurance, obsolescence, and financing. Calculate the holding cost per unit per year, considering factors like storage space requirements, interest rates, and inventory carrying costs

However, it's important to consider factors like lead time variability and seasonality. Inventory management software automates inventory tracking, offers real-time visibility, and provides predictive capabilities (El Jaouhari et al., 2022). It streamlines order fulfillment processes and integrates with other business tools. Investing in inventory management software can enhance efficiency, reduce costs, and increase customer satisfaction.

This includes maintaining proper inventory levels to avoid stock outs or overstocking at any time. Applying the right-time method has been suggested as an effective option to prevent the optimal stock-out.

Effective supply chain management and collaboration are essential for the success of company. Collaborative planning, forecasting, and replenishment (CPFR) are particularly important in strengthening supply chain management. When a company manages its supply chain well, it can enjoy several advantages, such as reduced maintenance costs, improved distribution, and better inventory management (Alahmadi & Jamjoom, 2022).

To make informed decisions and ensure smooth coordination among partners, it is crucial to have an efficient flow of information within the supply chain. Sharing information allows for quicker order fulfillment and supports activities like procurement and maintenance scheduling (Alahmadi & Jamjoom, 2022).

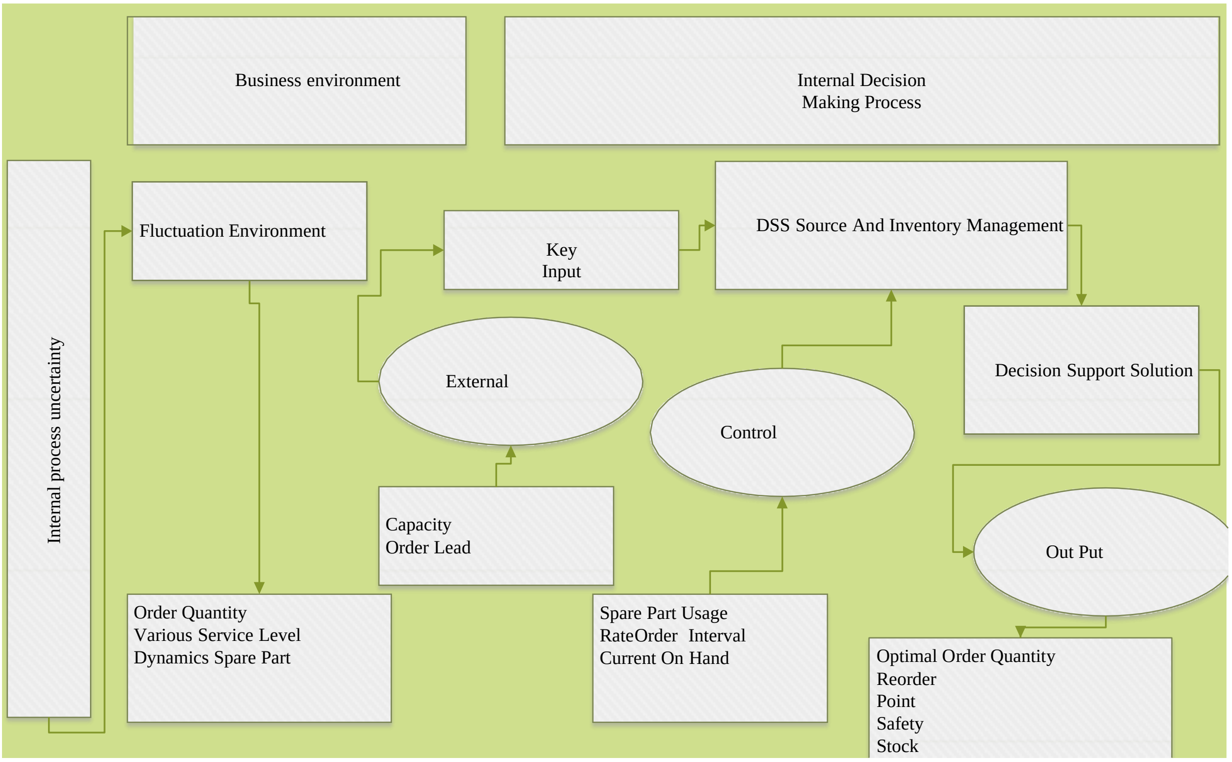


Figure 3:Conceptual Design of DSS drawing [author]

2.4. Maintenance and Repair Cost Management

2.4.1. Maintenance Management

The key components maintenance management are defining the maintenance strategy and implementing the strategy (Errandonea et al., 2020). The first part involves establishing the maintenance objectives, which are derived from the organization's business plan. This initial phase is crucial as it sets the foundation for the success of maintenance activities within the organization. The effectiveness of subsequent activities such as developing maintenance plans, creating schedules, implementing controls, and making improvements depends on the clarity and alignment of the maintenance objective (Al-Turki et al., 2019). Therefore, the definition of the maintenance strategy plays a vital role in improving the overall effectiveness of the maintenance management process. Therefore, the maintain of the maintenance strategy plays a vital role in shaping the overall effectiveness of the maintenance management process(Er-Ratby & Mabrouki, 2018). The second part of the process, the implementation of the selected strategy has a different significance level. Our ability to deal with the maintenance management implementation problem for instance, our ability to ensure proper skill levels, proper work preparation, suitable tools and schedule fulfilment (Silvestri et al., 2020).

2.4.2. Maintenance Cost

Different research explains the importance of controlling maintenance costs for construction equipment in the construction industry (Chong et al., 2019). It highlights that maintenance costs account for 15% to 37% of a machine's major costs over its service life (Thomas & Thomas, 2018). Accurately predicting maintenance costs is important for budget planning, resource allocation, and equipment management decisions (Yip et al., 2014).

Effective inventory management is crucial for optimizing inventory control and minimizing costs (Yip et al., 2014). Some organizations adopt a hybrid approach to strike a balance between inventory levels and spare part costs. Key components of spare parts management include maintaining a well-functioning parts supply chain, implementing real-time inventory systems, utilizing warehouse management systems, and integrating with enterprise resource planning (ERP) systems (Jenvald & Hovmöller, 2020).

The management of spare parts and supplies is a vital aspect of materials management, particularly when dealing with the random failures of construction equipment (Ramos et al., 2020). The objective is to ensure that equipment is in good working order when needed, and the availability of spare parts may be impacted by delays caused by unpredictable events. Such delays can have significant human and financial consequences. Additionally, equipment naturally undergoes wear and tear, necessitating the use of spare parts. If the necessary parts are not available, the equipment remains inactive (Kelly, 2021).

The utilization of technology, such as inventory management software, barcode systems, and RFID tracking, can streamline inventory management processes. The IoT revolutionizes inventory management and supply chains by providing real-time tracking, enhanced efficiency, predictive analytics, and improved decision-making(Mashayekhy et al., 2022). IoT devices enable accurate inventory tracking, optimize logistics, improve warehouse operations, and ensure regulatory compliance. They facilitate continuous improvement in the supply chain through the utilization of real-time data. By leveraging IoT technology, businesses can achieve cost-effective and efficient inventory management, leading to better visibility, reduced costs, and improved satisfaction (Masudin et al., 2021).

2.4.3. Proposed Conceptual Framework

Based on the existing theoretical and empirical literature, previous studies have individually investigated determinants of inventory performance, including inventory monitoring and ordering, control limits, replenishment decisions, and maintenance cost reduction.

To address this gap, the proposed conceptual model integrates all four determinants of inventory performance. By considering inventory monitoring and ordering, control limits, replenishment decisions, and maintenance cost reduction within a unified framework, the model offers a holistic understanding of their collective influence on inventory performance.

This comprehensive approach fills a research gap, providing a framework that examines the interplay between determinants of inventory performance. By analyzing the relationships between inventory monitoring and ordering, control limits, replenishment decisions, and maintenance cost reduction, researchers can gain valuable insights into the complex dynamics of effective inventory management practices.

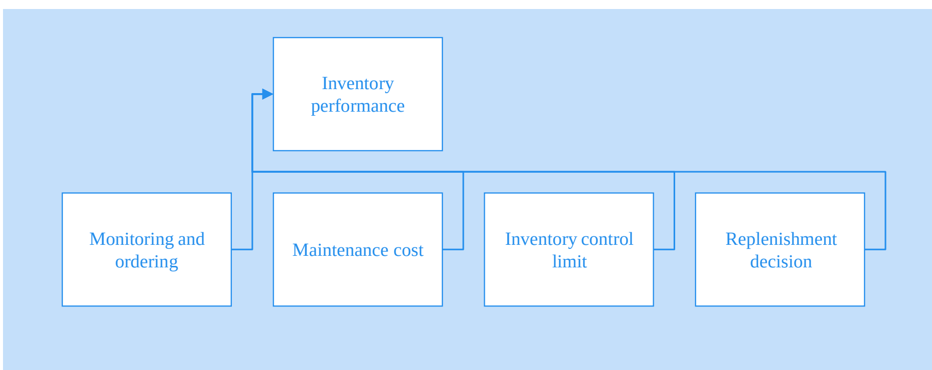


Figure 4: Conceptual Framework for Research [author]

The literature reviews a significant research gap in examining the relationship between inventory management practices and organizational performance in the construction industry. Although existing studies emphasize the importance of accurate demand forecasting(Hu et al., 2018), spare parts

Management(Muniz et al., 2021), and maintenance procedures(De Jonge & Scarf, 2020), there is little comprehensive research that directly examines the impact of an inadequate inventory management system on equipment maintenance performance, efficiency, and overall organizational success.

Furthermore, there are research gaps; for example, specific techniques or models for demand forecasting spare part requirement in the construction industry have not been identified. The studies have not been able to focus on the development of accurate forecasting methods prepared for the specific characteristics and challenges of the construction sector. This gap has forced construction companies to unproper optimize stock level.

The key research gaps related to the use of decision support systems (DSS) in inventory management are:

- There is a lack of thorough exploration on how DSS can be customized to cater to the unique requirements of supply chain management, especially for small and medium-sized enterprises (SMES).
- Insufficient empirical studies on the practical application and impact of DSS in enhancing control decisions and supporting decision-makers within supply chains.
- The integration of emerging technologies like AI and blockchain into DSS for supply chain management.
- There is a lack of comprehensive research on the effects of DSS on critical aspects of supply chain operations, such as cost reduction, efficiency improvements, and sustainability practices.
- The lack of studies on integrating Industry 4.0 concepts with circularity for sustainable value creation and designing strategic frameworks aligned with organizational goals.
- There is a gap in understanding how the integration of IOT systems can optimize inventory management processes and how traditional inventory replenishment policies need to evolve to adapt to modern technologies.

To address these gaps, current research aims to develop a comprehensive understanding of the relationship between ineffective inventory management practices and minimizing repair cost within the case company. This increases demand forecasting accuracy by improving data analysis and historical data analysis to anticipate and meet efficiency needs. In addition, the study provides recommendations and implementation strategies to enhance spare parts management, reduce maintenance costs and improve operational efficiency in the fleet; Increasing awareness of inventory management practices, technology adoption and maintenance will also be explored.

In addition, the study will provide insights to optimize maintenance procedures to reduce costs, reduce equipment downtime. This results in cost savings and increases equipment reliability. By addressing this research gaps, this study aims to contribute to a deeper understanding of how ineffective inventory management practices company performance.

At the conclusion of this research, we will have a deeper understanding of the importance of incorporating efficient inventory management systems and repair cost. This study used important insights into the importance of accurate demand forecasting, spare parts management and maintenance practices, and provides recommendations and implementation strategies to improve inventory management, reduce maintenance costs and improve maintenance efficiency in the case company.

CHAPTER THREE

3.Research Methodology

3.1 Introduction

The planning and methodology of a research study are road map in charting the path towards achieving the desired outcomes. In this research thesis paper, our approach will be comprehensive as we research into examining the relationship between inventory management and repair costs, with a specific focus on the significance of spare parts management and maintenance practices. this research methodology involves several key steps.

Firstly, we will analyze historical maintenance records to identify patterns of equipment failures and the factors contributing to repair costs and evaluate the effectiveness of preventive maintenance strategies in reducing such expenses.

Secondly, we will collect data on spare parts inventory levels and evaluate their availability during repair requirement. This will enable us to assess the impact of stockouts on repair costs, providing valuable insights into the relationship between inventory management and maintenance expenses.

Different data analysis techniques available to help identify the relationship of inventory and repair cost, such as implement transaction processing systems, management information systems, and decision support systems to achieve high-quality inventory management, reduce maintenance costs, and ensure the good inventory management systems.

Transaction process system (TPS) is designed to handle and process routine, day-to-day transactions and operational tasks of an organization while management information system (MIS) systems focus on collecting, organizing, and presenting summarized information from various sources within an organization to support managerial decision-making. In particular this research paper decision support systems (DSS) will be our preferred choice due to their specialized design for supporting decision-making processes. DSS systems offer relevant information, analytical tools, and models that can be tailored to different decision contexts and user requirements. They provide interactive and user-friendly interfaces, facilitating data exploration, analysis, and scenario evaluation. By incorporating decision-making support tools such as data mining, demand, optimization, and visualization, DSS systems enhance the decision-making process.

However, Decision support system provide real-time or near real-time access to timely information, enabling informed and timely decision-making. Their emphasis on decision support knowledge and methodology, including best practices, decision models, and analytical techniques, ensures the reliability and effectiveness of the research findings.

In summary, our methodology aims to develop a comprehensive understanding of how spare parts management and maintenance practices influence the dynamics of maintenance costs within the context of inventory management. By employing a well-designed approach, incorporating data analysis techniques and leveraging DSS systems, we anticipate gaining valuable insights that can contribute to optimizing inventory management and reducing repair costs in practical settings.

3.2 Research Design

The research design for this study focuses on gathering and understanding of the subject by collecting both primary and secondary data from internal stakeholders within the company. The primary data will be collected using methods such as observations, interviews, and historical data for secondary data available within the organization.

Primary data collection through observations involves directly observing and documenting the relevant processes, activities, related to spare parts inventory management and repair costs. This provides firsthand information and capture real-time insights.

Interviews will be conducted with internal stakeholders, including management staff, maintenance personnel, and inventory management staff. The interviews will involve face-to-face communication to gather detailed perspectives, experiences, and expertise. By engaging in direct discussions, can obtain valuable qualitative data that helps uncover challenges, practices, and decision-making processes related to spare parts inventory management and repair costs.

In addition to historical data available within the organization, such as inventory management, reports, documents used for secondary data sources, and lead time. Analyzing this secondary data provides a broader context and identify patterns, trends, and areas for improvement in spare parts inventory management and repair costs.

Both primary and secondary data collection methods, for this research design get comprehensive and reliable information. This approach enhances the accuracy and validity of the research outputs and facilitates the development of effective strategies for improving spare parts inventory management and reducing repair costs within the company

3.3 Data collection

The data collection process for the research on inventory management in case company involves several methods, including observation, interviews, and questionnaires. Benchmarking is used to gain insight into current work practices by interviewing employees from different departments.

Both qualitative and quantitative data collection methods are used to ensure a descriptive approach, using both primary and secondary data sources. Primary data will be collected through direct observation, semi-structured interviews, which will provide direct information from key informants. Secondary data sources, such as articles, journals, reviews, reports, documents and visual aids related to spare parts inventory management are recommended to support and confirm the findings from the primary data collection.

3.3.1 Observation

During the observation phase of developing Sunshine Construction's parts inventory management decision support system (DSS), specific areas such as , maintenance department, spare part main Wearhouse on Gelan workshop. On-site observations are carried out to collect information on inventory levels, stock management practices, sequence of orders, usage patterns, maintenance procedures, documentation and record keeping. Challenges and obstacles are identified and documented. The observations collected are analyzed and interpreted to guide the design of the DSS. The ultimate goal is to reduce maintenance costs, increase the efficiency of maintenance operations and improve inventory management system on Sunshine Construction company.

3.3.2 Interview

This study is to collect information about the inventory and maintenance management system in the Sunshine construction. Interviews with these key informants are conducted to gather general information on inventory management, identify challenges in this area and explore opportunities for improvement, and for clarity that gather by observation. The interview questions covered a variety of topics including tracking and tracing of spare parts inventory, sorting and storage practices, techniques used for inventory control, decision-making processes for re-ordering spare parts, spare parts usage patterns, documentation and recordkeeping. Practices, communication and collaboration among stakeholders, cost drivers and efficiencies, and opportunities to optimize spare parts utilization and reduce maintenance costs. Specific interview questions and information about key informants are listed in appendix A;

3.4 Literature Review

The literature review section of the thesis proposal examines the inventory management in the construction industry. It focuses on several key areas, including optimizing stock levels, lead-time, decision support systems (DSS) in inventory management, and maintenance and repair cost control.

One of the main issues identified in the review is the effective management of reducing maintenance costs. This includes considering the impact of spare parts management on maintenance demand. Accurately predicting maintenance costs related to equipment maintenance and replacement is critical to asset allocation and decision making.

The reviews explore the role of inventory policies in controlling spare parts inventory throughout the product life cycle. It considering strategies such as the (s, s) policy and the (q, r) policy, which are typically used to maintain the optimal level of inventory and reduce inventory risk.

In addition, the reviews emphasize modern inventory management technologies and decision support systems (DSS). These tools can improve inventory control and facilitate informed decision-making processes. By analyzing historical data and spare parts demand, companies can make better decisions about inventory replenishment and avoid excess inventory.

In addition, the reviews emphasize the importance of effective collaboration and information sharing to achieve efficient spare parts inventory management. In their assessment, they tried to put that collaboration between different stakeholders like maintenance teams, warehouse team and procurement departments can lead to improved inventory control and better overall results.

Overall, the thesis aims to improve inventory performance, reduce costs, and promote business success in inventory management in the construction industry. The study aims to contribute to the development of inventory management practices by adjusting the inventory management of various spare parts in the Sun Construction Company. This includes consideration of factors such as demand forecasting, inventory policies, maintenance cost control, and technology integration. By exploring these areas and providing innovative solutions, the study aims to improve product performance, reduce costs and bring about business success in spare parts management at Sun Construction Company.

3.5 Source of Data

In research, data can be obtained from a variety of sources, depending on the nature and objectives of the study. The two main types of data sources are primary and secondary.

When selecting data sources for this study, the research objectives, the chosen methodology, and ethical consideration. The data sources should provide relevant and reliable information that can answer the research questions or test the hypotheses. Often, a combination of primary and secondary data sources will be used to gather comprehensive and reliable data for the study. The choice of data sources will be made strategically to ensure the validity and robustness of the research findings

3.5.1 Primary Data Source

The data collected from primary sources would be used in both quantitative and qualitative data types.

Quantitative data is numerical in nature and involve measurement of variables. In the context of spare parts inventory management and repair costs, quantitative data can be obtained through various primary data collection methods within the company. For this research by observing exciting system gathering the following:

Existing company data on inventory levels and stock requirements: By observing and recording the inventory levels of spare parts at different time points, collect quantitative data on the quantity and availability of stock.

Repair costs related to spare parts and labor: collect quantitative data on repair costs by directly recording the actual expenses incurred for spare parts replacements, labor charges, and associated costs.

Maintenance cost: By analyzing historical maintenance records and conducting interviews with maintenance staff, gather quantitative data on maintenance costs, including the expenses associated with maintenance requirements, repairs, and failure rates.

These quantitative data used to identify patterns, trends, and relationships between inventory and repair cost. This analysis can provide insights into the effectiveness of the current spare parts inventory management practices and the associated repair costs with in the company.

Qualitative data also, which is valuable insights into the experiences, perspectives, and opinions of individuals engaged in spare parts inventory management and maintenance. By conducting interviews and making observations, collect qualitative data that aids in comprehending the underlying factors, challenges, and decision-making processes associated with inventory management and repair costs.

3.5.2 Secondary Data Source

Secondary data will be collected from Sunshine Company, reports, and Written documents, on the subject matter, inventory, and maintenance activity existing system related to historical data spare parts available, demand pattern, and lead time.

3.6. Method of Data Analysis and Tools

This paper utilizes quantitative approaches to study, the data collected will be calculated by excel , to set the rank the items based on their select criteria, and item demand data, lead times, or other factors used for categorization respectively, and (EOQ) Mathematical analysis of economic order quantity Model used to determine the optimal .

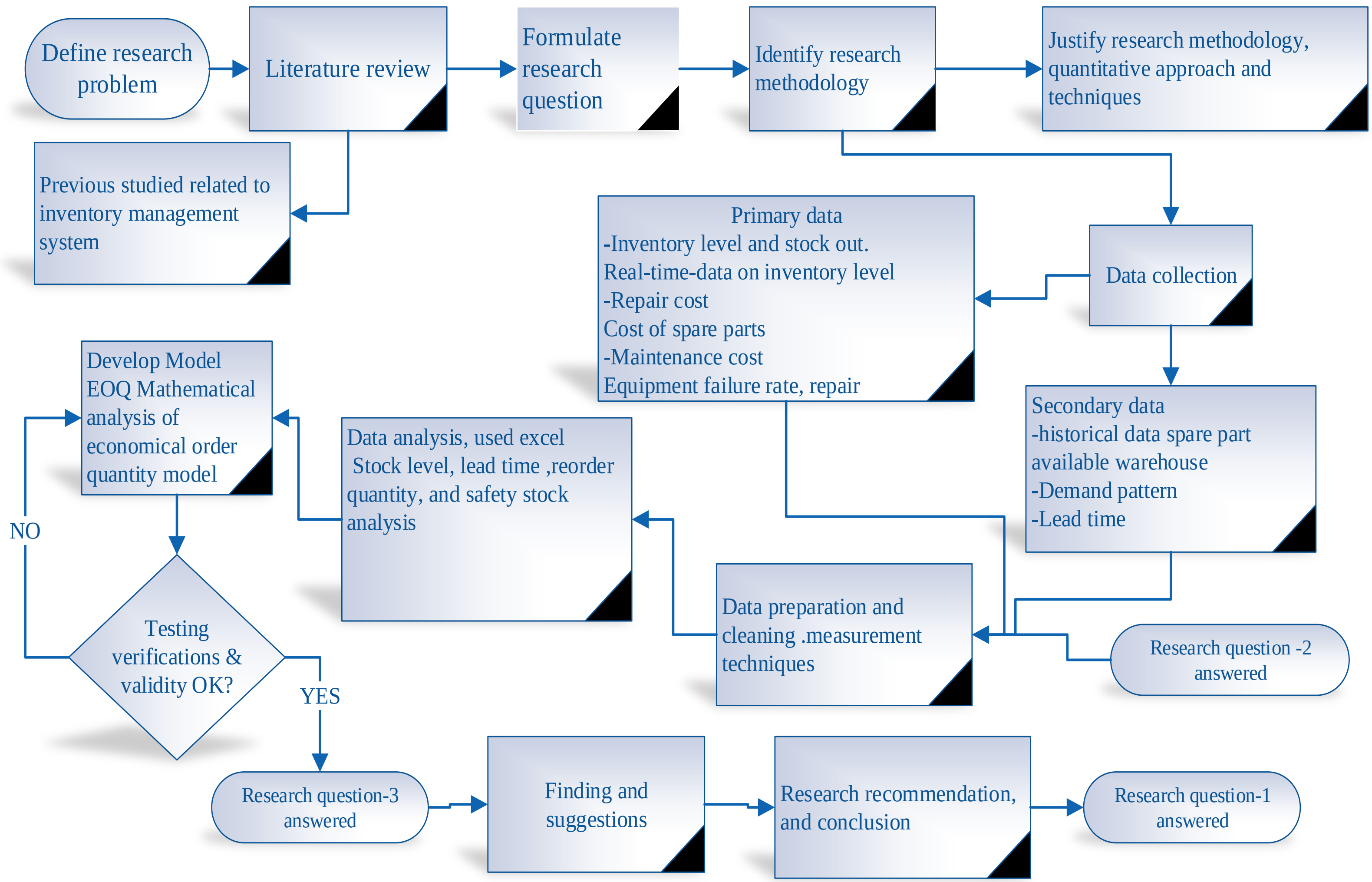


Figure 5:Methodology Framework

The research methodology for this study was designed to address the research questions raised, and it involved the following phases:

First, specifically focusing on optimizing stock levels and leading time , communication among internal departments to accurate information flow, and how can organization develop a decision support system .Next, conduct an extensive literature review to gather knowledge and best practices related to inventory management by different author perspective, inventory optimization, and lead time improvement to identify relevant theories, methods, and information flows.

The next step involves collecting relevant data to provide a basis for analyzing and improving inventory management practices in spare parts management, including information on stock levels, lead times and maintenance costs. After the data is collected, selects data analysis tool and model based on the research question and the available resources. In this case, utilizes the FMEA analysis tool and the EOQ (Economical Order Quantity) model.

This may employ mathematical optimization models, decision support systems, and statistical analysis as part of the chosen methods. These tool and model are carefully selected to align with the research objectives and facilitate the development of effective models. Range of statistical techniques and procedures to explore, classified and interpret the data. This can include descriptive statistics, and regression analysis by using SPSS data analysis tool.

In addition, integrated these EOQ model into the analysis. The EOQ model is an inventory management technique that used to determine the optimal order quantity that minimizes total inventory costs. By incorporating this model, the study can assess and optimize inventory management practices in relation to the research question. The models are built to take into account various factors such as demand patterns, lead time variability, cost estimation and service level requirements, focusing on the methods chosen to optimize stock levels and lead time.

The results of the models are used to analyze different scenarios and evaluate possible strategies. this allows for a comprehensive assessment of the inventory management approaches on stock levels and lead times. Then tested to ensure the verify and reliability of the models. This verification process helps to ensure efficiency in representing the complexity of spare parts management.

After the analysis and testing is completed, the results are interpreted to a meaningful conclusion, the research findings and recommendations will contribute to the existing knowledge in construction equipment maintenance and inventory management. They will provide valuable insights for future research and assist other companies in the industry facing similar challenges. By addressing research gaps and proposing innovative solutions, the research will advance the understanding and practices in inventory management, technology adoption, and maintenance within the construction sector.

3.7. DSS Framework Development for Inventory Management in case company.

Sunshine Construction Company's primary challenge is the cost of equipment maintenance due to inefficient inventory management and maintenance practices. Decision support for inventory management and maintenance optimization is fundamental to solving this problem. A Decision Support System (DSS) has key features that can address this issue, such as better inventory optimization based on historical data, demand patterns and lead times, as well as types of equipment failures. The DSS can also facilitate a maintenance schedule to ensure maintenance is done at the right time, and include parts management to track usage, monitor finish, and recommend replacements. Additionally, the DSS's comprehensive reporting and analytics capabilities can help Sunshine Construction Company make data-driven decisions.

Key issues to consider in the implementation of the DSS include detailed historical and current inventory data, demand and consumption status, financial data and supplier data, as well as maintenance history and equipment information including comprehensive maintenance records, equipment specifications and failure information. The DSS should also incorporate resource information, equipment usage, maintenance budgets and costs, and return on investment for maintenance operations, and identifying opportunities for improvement, and aligning with a case company core business objective.

By addressing these key issues and implementing the recommended DSS features, a case company can significantly reduce maintenance costs, improve equipment reliability and availability, and increase the overall efficiency and profitability of their construction operations. The adoption of an interactive, computer-based information system like a DSS will be particularly useful for Sunshine Construction Company in managing their inventory and maintenance optimization.

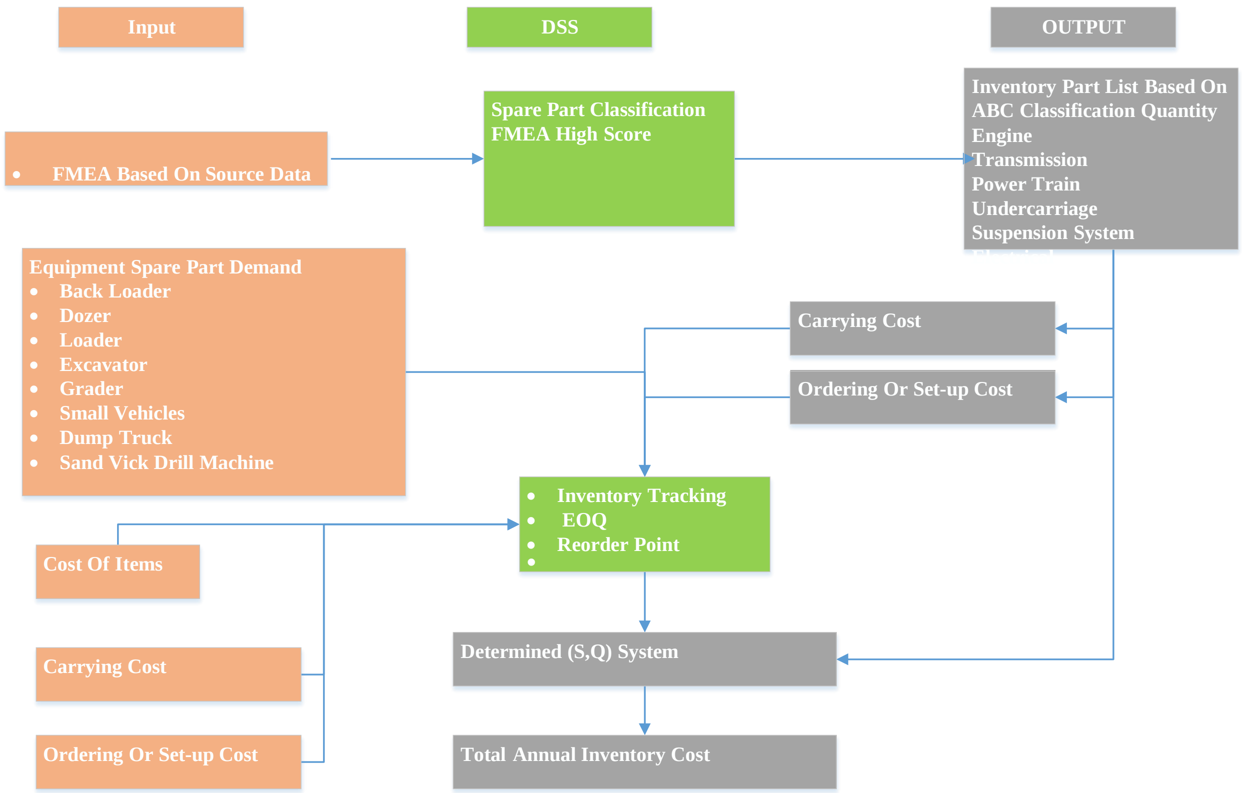


Figure 6: Model Framework for DSS Developed [by author]

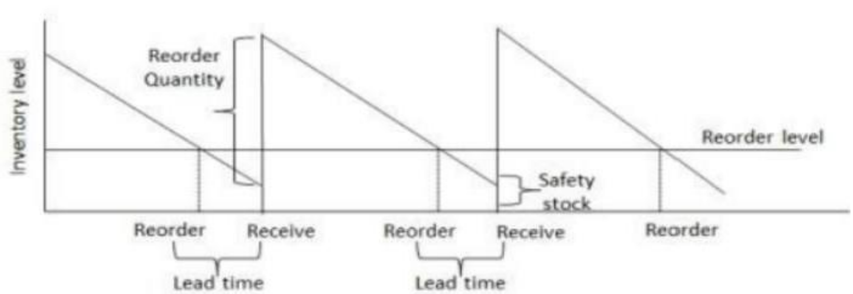


Figure 7:Inventory Tracking [source:(Moradizadeh, 2019)]

Inventory tracking a crucial role in our model, as it facilitates the coordination between the inventory department and the maintenance department. The inventory state is managed using a deterministic model that incorporates the concepts of reorder point and economic order quantity, as depicted in Figure above.

When the stock level decreases to a specified reorder point, an order is placed with the supplier for a lot size known as the economic order quantity. After an order is placed, the warehouse manager ordered items to replenish the inventory, which occurs during a lead time. The lead time represents the time gap between when the order is placed with the received.

Accurately estimating the lead time for a new order (L) can be challenging, especially when faced with different scenarios that make it difficult to easily access. In such cases, the application of thumb rules can still be beneficial.

When dealing with a new order where the lead time (L) is not readily available, thumb rules can serve as a starting point for the estimation process. These simple, rule-of-thumb guidelines can provide a reasonable baseline for the expected lead time Lead time new order (L) difficult to easily access because at different scenario, for this thumb rule apply, the challenging conditions of high ordering process complexity, frequent order modifications, supplier unreliability, and extensive documentation requirements, there are still scenarios where the application of thumb rules for lead time estimation may be appropriate.

Thumb rules that can help in estimating lead times based on demand levels, for this some constant and coefficient mention as the following tables.

Table 2: [Estimated Lead Time Based on Thumb Ruel, Source:(Baker, 1994),(Chopra & Meindl, 2001),(Rahimi-Ghahroodi et al., 2019)]

It	Conditions	Constant	Coefficient’s	Estimating
1	Make-To-Stock A Product	a		2-4 Weeks
2	Make-To-Order A Product	a		4-8 Weeks
3	Highly Customized Product	a		8-12 Weeks
4	Low Complexity and High Volume		b	0.01-0,03 Days/Unit
5	Medium Complexity and Medium Volume		b	0.03-0.06 Days/Unit
6	High Complexity and low volume		b	0.06-0.1 Days/Unit

Once you have determined the values for 'a' and 'b', you can apply the lead time formula:

$$Lead\ time = a + b * demand \qquad (21)$$

To ensure maintenance efficiency, the maintenance department plays a crucial role in determining the reorder point and economic order quantity. They provide information and insights regarding the maintenance requirements and the expected usage of spare parts. This collaboration allows for more accurate inventory management decisions and reduces the risk of stock-outs or excess inventory. Additionally, the concept of safety stock is considered in this collaboration between the inventory and maintenance departments. Safety stock refers to the additional stock held by a company beyond its requirement for the lead time. This buffer stock is maintained to safeguard against potential stock-outs due to unexpected variations in demand or delays in the supply chain.

3.8. Optimal Economic Order Quantity (EOQ)

In a continuous, or fixed order quantity system when inventory reaches a specific level, referred to as the reorder point, affixed amount is order, EOQ is an important management system that demonstrates the quantity of items to reduce the total cost of both handling of inventory (handling cost) and ordering process (ordering cost)(Munyaka & Yadavalli, 2022). The purpose of determine the EOQ is to minimize the total incremental cost (TIC), beyond the cost of purchasing of spare parts, in considering of two main total cost. For this, Mathematical approaches and emphasizes the mathematical model as highly useful to enhance the inventory management.

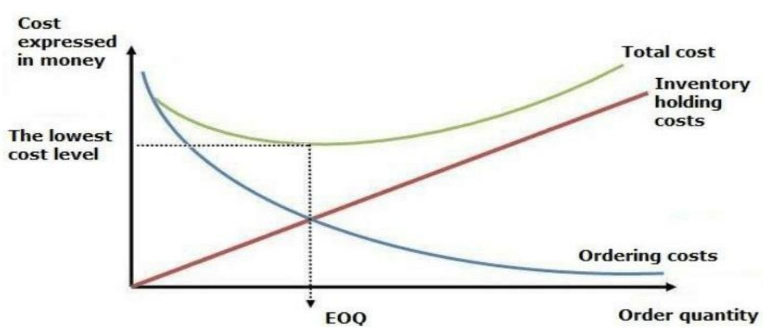


Figure 8: [Optimal Economic Order Quantity Point source:(Tien et al., 2019)]

Particularly, from purchasing point view, TOC, and THC are the additional cost, which incur above cost of a material purchased, Therefore, aggregation of both cost (TOC, THC) are known as total incremental cost, i.e (Munyaka & Yadavalli, 2022).

$$TIC = TOC + THC \qquad (22$$

Were, THC-total handling cost,

TOC- total ordering cost

CHAPTER FOUR

4. Data Analysis and discussion

4.1. Introduction

In The Context of Maintenance and Inventory Management, Our Focus Shifts from Components Required for Assembly to Identifying critical equipment, machinery, or systems that require maintenance. The goal is to ensure an adequate inventory of spare parts to support maintenance activities. This involves assessing the maintenance requirements of different assets and establishing an inventory of spare parts for each.

Lead time in maintenance refers to the time required to procure or receive spare parts or equipment for maintenance purposes. It is crucial to consider the lead time when ordering and receiving spare parts to ensure timely maintenance. Additionally, delivery time plays a vital role in ensuring that the spare parts are promptly delivered to the maintenance team once they are received.

Component replenishment in the maintenance context involves restocking spare parts or equipment after maintenance activities, anticipating changing maintenance requirements. It is essential to maintain an optimal level of inventory to minimize downtime and ensure smooth maintenance operations.

To optimize decision-making in maintenance and inventory management, the development of a Decision Support System (DSS) is beneficial. The DSS should provide a comprehensive view of inventory levels, maintenance requirements, and key decision variables such as reorder points, costs, and equipment downtime. By offering valuable insights and analysis, the DSS assists maintenance managers in making informed decisions to optimize maintenance operations and inventory management.

To develop an optimized decision support system (DSS) model that links the maintenance and inventory based on both observation and recording data, using different optimization techniques.

4.2 Current Inventory Controls the Company

According to the information obtained from the case Company employs various inventory control practices, including Enterprise Resource Planning (ERP), the straight-line method, physical inventory control systems, and periodic inventory control practices. While the straight-line method involves arranging materials in a straight line to facilitate visualization and identification without any information related to maintenance requirement, the ERP (Enterprise Resource Planning) systems are currently used for controlling inventory status for only financial purposes but have limitations when it comes to analyzing optimal ordering quantities, timing, and frequency of spare parts. ERP alone is not sufficient for effective inventory control and planning, and to achieve better outcomes in inventory management.

In addition to the existing inventory control methods, the company should consider implementing the Economic Order Quantity (EOQ) inventory control technique. This technique can help improve overall inventory control and planning for the spare parts by analyzing the holding cost, annual setup cost, expected number of order quantity, inventory levels, and reorder points for each unit of spare parts using the available data. Incorporating EOQ analysis into the DSS framework can provide valuable insights to further optimize inventory levels and reduce repair costs for this company.

4.3 Failure Mode and Effect Analysis (FMEA)

To develops predictive maintenance model by utilize the equipment down status and failures. Failure Mode and Effects Analysis (FMEA) is a systematic approach used to identify potential failure modes of a system, process, or component, and evaluate their effects and severity. It helps prioritize resources and develop strategies to prevent or mitigate failures. For this specific research FMEA can be applied to identify critical failure modes follows these procedures. For this participate different expertise and select by the following procedure and criteria.

	Recommend	**Details**	**No. Expertise's**	**Related Research**
1	Identify Key Stakeholders and Experts	- Engage with the maintenance, operations, and procurement departments at Sunshine Construction Company to identify the most experienced and knowledgeable personnel involved in spare parts management and equipment maintenance.	17	Ali, M. A., & Ratnayake, R. M. (2023)
		Consider including experts from the engineering teams who have a deep understanding of the equipment and failure modes used at Sunshine Construction.	8	Atnafu, D., & Balda, A. (2018)
2	Establish Criteria for	- Define the minimum qualifications and experience required for the FMEA experts, such as at least 5 years	Require at least 5 years of	Alahmadi, M. M., & Jamjoom, M. B. (2022)

	Expert Selection	of experience in the construction industry, specific knowledge of the equipment and processes used by Sunshine Construction, and familiarity with FMEA methodology.	experience in the construction industry and FMEA methodology.	
Education Qualification of the interview minimum 5 year experienced				
		Frequency	Percent	Cumulative Percent
	College diploma	14	56%	0.56
	First Degree	8	32%	0.88
	Second Degree	3	12%	1

1. First Identified the Component and Functions

Table 3: Equipment Components and Function Failure Type

S/N	Equipmen tType	Asset Plate No	Date In	Down Reasons and Job Orders
Dozer				
1	Dozer	Emm01-12	6/5/2015	Engine overhaul, final drive, and transmission systemfailures, hydraulic
2	Dozer	Emm01-16	29/8/2015	Engine overhaul needs, hydraulic
				Final drive failure
				Undercarriage wear
3	Dozer	Emm01-17	16/09/2015	Under carriage, electric system, transmission over heating
4	Dozer	Emm01-22	6/11/2015	Engine overhaul
				Transmission system
				Under carriage, electric system,
				Control valve malfunction
				Final drive
5	Dozer	Emm01-13	19/12/2015	Engine overhaul
				Main hydraulic pump failures
				Undercarriage wear
				Final drive damaged
				Brake system
				Transmission system failure
6	Dozer	Emm01-33	23/03/2016	Equalizer bar bearing damage, oil leakage, front crankshaft seal leakage.
Loader				
1	Loader	Emm02-09	26/04/2015	Control valve, engine gasket, starting system, oil leakage,hydraulic
2	Loader	Emm02-20	25/12/2015	Transmission gear shifting system, brake system
3	Loader	Emm02-18	13/03/2015	electrical system, ECM, turbocharger
Back loader				
1	back loader	Emm 02-2	5/5/2015	Engine overhaul
Excavator				
1	Excavator	Emm03-18	4/11/2015	Bucket pin, and bushing wear, water pump, under carriageand rollers wear out, hydraulic system
2	Excavator	Emm03-21	17/12/2015	Hydraulic main pump, hydraulic control valve, engineoverhaul
Grader				
1	Grader	Emm04-07	20/7/2015	Engine overhaul, and transmission control valve, electricalsystem, hydraulic system
2	Grader	Emm04-08	13/9/2015	Engine overhaul and electrical system, hydraulic system
3	Grader	Emm04-14	29/11/2015	Engine overhaul, control valve, brake system, transmission
4	Grader	Emm04-09	24/3/2016	Transmission, engine overhaul, hydraulic system,

drill				
1	Sandvick drill	Emm07-01	2/2/2016	Hydraulic system, control valve
				Drifter, different filter, seal kit
				Fuel system
Dump truck				
1	Dump truck	3-A05545	11/7/2015	Suspension system, tandem housing, cross member,
2	Dump truck	3-35869	20/7/2015	General service, electrical system, clutch system, PTO pump
3	Dump truck	3-28228	14/10/2015	Engine power loss, brake system, electrical system
4	Dump truck	3-A05479	25/03/2016	Front and rear differential, brake system, electrical system
5	Dump truck	3-28231	3/4/2016	General service, electrical system, dumping body.
6	Dump truck	3-89532	23/04/2016	Engine over haul, suspensions system
Toyota pick up				
1	Toyota pick up	3-27405	17/08/2015	Engine over haul and electrical system
2	Toyota pick up	3-14189	16/12/2015	Engine overhaul, body damage and paints, all electrical systems
3	Toyota pick up	3-A26010	12/2/2016	Engine over haul, suspensions system
4	Toyota pick up	3-82619	25/02/2016	power train, brake system, electrical system
5	Toyota pick up	3-A26011	20/03/2016	Engine over haul and general service, suspension system

2. For Each Component or Function the Possibility Failure Modes

The major system can failure modes related to various components or functions. These failure modes include issues with the fuel system, combustion system, electrical system, excessive oil consumption, and mechanical parts exhibiting wear or damage, the expertise giving a rank value from (1 to 10)(Antosz & Ratnayake, 2019).

Table 4: Components or Function the Possibility Failure Modes

	Item/ Function	Potential Failure Mode	Potential Effect	occurrence	Potential Cause	Severity	Detection	Risk Priority Number (RPN)
1	engine	Piston ring wear or breakage	Loss of engine power and efficiency	9	Normal wear and tear over time and usage	8.2	6.34	442.21
		Connecting rod wear or failure	Increased oil consumption andleakage	9	Excessive loads, speeds, or operating conditions	8.76	6.39	475.48
		Crankshaft and bearing wear orfailure	Coolant leaks and overheating	7	Lack of proper lubrication or maintenance	8.78	6.73	413.73
		Oil burning or leakage	Misfiring, rough running, or enginestalling	9	Overheating or thermal stress	7.56	7.02	450.98
		Valve mechanism wear orfailure	Damage to other engine components due to mechanical failures	9	Manufacturing defects or poordesign	8.38	6.98	496.90
		Coolant leaks	increased fuel consumption andincreased emissions	6	Incompatible or poor-quality replacement parts	7.84	7.27	313.52
		Cylinder head cracking orgasket failure	air babble on radiator, engineoverheating	7	Fuel/air mixture issues orincomplete combustion	8.91	6.89	429.71
		Cylinder liner and block wear orcracking	engine overheating, additionalcoolant needs	6	Environmental factors like dust, debris, or corrosion	9.11	6.49	354.73
		improper timing, air fuel ratio incorrect, valve clearance adjustments incorrect	Incomplete combustion issues	9		8.73	6.82	536.23

2	transmission	Inadequate lubrication or oilsupply	Increased wear and tear on transmission components	7	Insufficient or improper transmission fluid maintenance	8.44	6.62	391.45
		Harsh or abnormal shiftingtechniques	Difficulty shifting gears or erratictransmission operation	7	Operator inexperience or poorshift technique	8.56	6.40	383.29
		Wear or failure of gears, bearings, shafts, and synchronizing parts	Loss of power transmission anddriveline failure	5	Normal wear and tear over time and usage	8.84	6.86	272.85
		Wear or failure of friction platesand discs	Leaks and contamination oftransmission fluid	5	Excessive loads, speeds, or operating conditions	8.56	6.81	262.23
		Seal wear or failure	Overheating and damage to internalcomponents	6	Incompatible or poor-quality replacement parts	7.84	6.46	303.84
		Overload or excessive operating conditions			Lack of proper lubrication or seal integrity			**391.45**
3	hydraulic	Worn or leaking seals	Hydraulic fluid leaks and loss of system pressure	8	Normal wear and tear over time and usage	8.29	6.24	414.08
		Worn or damaged hoses	Reduced efficiency and performance of hydraulic components	6	Exposure to harsh operating conditions, temperature extremes, or contaminants	8.62	6.63	343.16
		Wear or failure of internal hydraulic components	Accelerated wear and failure of hydraulic pumps, motors, and cylinders	6	Improper maintenance or replacement of hydraulic components	8	6.71	322.13
		Contaminated or insufficient hydraulic oil	Overheating of the hydraulic system	7	Inadequate or improper hydraulic fluid selection and maintenance	7.8	6.49	354.29
		Hydraulic oil cooling system issues	Erratic or unpredictable behavior of hydraulic-powered equipment	5	Cooling system malfunctions, such as fan failures or blockages	7.53	6.07	228.51
		Air entrainment in the hydraulic system	Potential for damage to other machine components	7	Air leaks in the hydraulic system or improper bleeding/purging	8.22	6.76	388.82

								414.08
4	brake	Wear and deterioration of brake system components	Reduced braking performance and efficiency	8	Normal wear and tear over time and usage	8.36	6.89	431.70
		Wear or failure of brake discs and friction plates, pad lining, shoe	Uneven or premature wear of brake components	7	Operator error or excessive braking force application	7.78	6.49	353.28
		Inadequate maintenance and servicing	Increased stopping distances and potential safety hazards	9	Use of low-quality or unsuitable brake materials	7.78	6.49	428.99
		Vacuum seal leaks in the brake booster system	Increased risk of brake system failure or loss of braking control	7	Lack of proper maintenance, inspection, and servicing	7.78	6.49	353.28
								431.70
5	power train	Wear or failure of internal and external parts:	Fluid leaks and loss of system pressures	6	Normal wear and tear over time and usage	9.62	6.63	351.05
		Seals, shafts, bearings friction disc, pressure plate	Reduced efficiency and performance	8	Exposure to harsh operating environments	8.4	6.31	397.60
		Discs, plates	Accelerated wear and damage to other components	6	Lack of proper maintenance and servicing	9	6.47	320.10
		Hoses, pipes, fittings	Potential for sudden or catastrophic failures	6	Use of inferior or incompatible replacement parts	8.17	6.95	340.67
					Overloading or exceeding the equipment's design limits ,drive long distance, use beyond design jobs			
					Operator errors or improper handling of the equipment			
								397.60
		Improper adjustments and maintenance	Potential for track failure	7	Improper adjustments, improper maintenance, or lack of regular inspections	7.5	7.50	393.75
		Hydraulic system issues:	Hydraulic fluid leaks and loss of system pressure	5	Hydraulic system issues, such as leaks, contamination, or component wear	6.29	4.97	156.17

		Leaks in hoses and fittings	Reduced efficiency and performance of the hydraulic system	6		7.29	5.20	227.41
		Wear or damage to cylinder shafts and rods	Potential for damage to other machine components	8		5.4	4.38	189.17
								393.75
7	suspension	Wear and deterioration of internal and external suspension components:						
		Bushings, seals	Reduced ride quality and vehicle stability	9	Exposure to harsh operating environments and heavy loads	7.87	6.20	438.96
		Weak or damaged springs	Increased stress on other suspension and chassis components	7	Improper maintenance, adjustments, or replacement of worn parts	7.71	5.61	281.16
		Improper tire inflation pressure	Potential for suspension component failure and loss of vehicle control	6	Use of incorrect or incompatible suspension components and fluids	7.93	5.98	284.30
		Use of incorrect tire size	Accelerated wear and damage to tires, wheels, and other related parts	8	Operator errors or lack of attention to suspension and tire maintenance	7.9	6.15	389.22
			Operation in harsh working conditions	6		7.9	6.15	291.91
			Delayed replacement of worn parts	6		6.5	7.50	292.50
			Lack of regular, proper maintenance	5		6.98	5.00	174.40
								438.96
8	electrical	Electrical system issues:	Reduced system performance and efficiency	7	Operating the equipment under excessive loads or in harsh environments	6.98	5.89	287.65
		Sensor or control component failure due to wear, calibration issues, or damage	Increased risk of component failure and breakdowns	8	Improper installation, calibration, or maintenance of electrical	6.98	5.95	332.12
		Wiring and connection problems, including corrosion and vibration damage	Inaccurate sensor readings and control issues	6	Wear and deterioration of electrical and mechanical parts over time	7.02	6.01	253.30

		Wear or failure of electrical components like bearings, bushings, and fans	Damage to other related components due to electrical or mechanical problems	6	Lack of regular inspections and proactive replacement of worn components	6.24	5.71	214.01
		Improper installation, adjustment, or wear of components like V-belts		-	Vibration, corrosion, and other environmental factors			
		Delayed replacement of worn or damaged parts						
		Charging system malfunction						**332.12**

2. Assign Severity Ranking

The Severity Rankings are assigned the above table based on the potential impact of failure modes on the system, considering factors like safety hazards, reduced performance, and overall system functionality.

3. Detection Ranking

These Detection Rankings are assigned on the above table based on the potential impact of failure modes on each system and the ability to detect these failures effectively as outlined in the observation data.

4. Risk Priority Calculation

To calculate the Risk Priority Number (RPN) for each failure mode, you can multiply the severity, occurrence, and detection rankings. The RPN provides a numerical value that helps prioritize actions based on the highest risks. To calculate the RPN first, assign a severity ranking to each failure mode, considering the potential consequences and impact on safety, performance, and costs.

Calculate the RPN: Multiply the severity, occurrence, and detection rankings together to obtain the RPN for each failure mode(Ciani et al., 2019).

RPN = Severity Ranking * Occurrence Ranking * Detection Ranking. (29)

In this case, the high RPN values indicate the most critical failure modes and areas of concern for the company's equipment and vehicles, as identified by company the experienced maintenance personnel.

The high RPN numbers highlight the major reasons and frequencies that the company's equipment is spending excessive down out of service. This information is valuable for the spare parts management team to prioritize and optimize their inventory, in order to reduce the lead time to obtain critical replacement parts and ensure the maintenance department can respond and resolve issues more quickly.

To address these high-priority issues, the company needs to assess what specific spare parts are needed most frequently, how much inventory of those critical parts should be maintained in the warehouse, and processes to expedite procurement and replacement of those parts.

Therefore, based on the above table, the engine function has the highest Risk Priority Number (RPN), indicating that it requires immediate attention. On the other hand, the electrical system has the lowest RPN, suggesting that it can be addressed with a relatively lower priority. This number indicates the reason and frequency of the company's equipment and vehicles being out of service for a long time. The number was obtained from 25 people who have served in company's maintenance sector for a long time and have qualified the experience in the field.

It also helps to identify the spare parts you need in relation to the engine of each vehicle or equipment to know the cost of each unit. FMEA analysis insights to drive their spare parts management strategy, the company can take proactive steps to minimize vehicle downtime and improve the overall reliability and performance of their fleet.

4.4 Economic Order Quantity (EOQ)

Economical order quantity (EOQ) is an important management system that demonstrates the quantity of items to reduce the total cost of both handling of inventory (handling cost) and ordering process (ordering cost). The purpose of determine the EOQ is to minimize the total incremental cost (TIC), beyond the cost of purchasing of spare parts, in considering of total holding and ordering process cost.

Inventory Holding Cost

Companies must store what is not in use, so the extra inventory should be held in the warehouse in case of shortage.

Holding costs various cost factors, such as warehouse storage cost, security measures to protect the inventory, insurance coverage to safeguard against potential losses, and any additional costs related to the preservation and management of inventory. Holding costs the entire inventory, not just the items currently in use.

It's important to note that holding costs are considered significant because they are incurred regardless of other costs, such as ordering costs or shortage costs. They are ongoing expenses that companies must bear as long as inventory is being stored.

To calculate holding costs accurately, it's crucial for businesses to consider all the relevant factors specific to their inventory management, including the costs associated with storage space, security, insurance, and protection of the inventory.

When estimating the holding or carrying cost per unit, there are several factors to consider. While the specific assumption may vary depending on the context and industry, here are some common factors to consider in this case company.

Table 5: Spare Parts Purchased Cost Incur Ordering Process

No	**Description**	**Allocable Accumulation Cost**	
1	Insurance	4,341.41	
2	Service Charge	63,334.55	
3	Customs Charge	158,336.37	
4	Fright Charge	102,918.45	
5	Storage Charge	118,752.22	
	Total Ordering cost per order (C_o)	447,683.00	
	Ordering cost per unit item order	447,683/95	4,712.5

Table 6:Holding or Carrying Cost Per Unit

No	**Category**		
1	Storage Cost (Expense Related to Physical Storage Space, Utility.	44,029	
2	Inventory Shrinkage (The Cost Related to With Inventory Accuracies', such safety employee theft installed camera system, and others	37400	
	Total holding cost	81,429	

Assumption of EOQ model develop

- The determination of the Economic Order Quantity (EOQ) for the inventory management at this case company consists of the following assumptions:
- The Economic Order Quantity (EOQ) will be determined for each individual spare part in the inventory.
- The amount of demand for spare parts is known. The DSS will be based on the expected annual demand for each exchange;
- The price of the order is known and constant the whole year. This includes the fixed costs associated with placing and processing each order, such as administrative costs.
- Spare parts handling cost is known and constant throughout the year. If the handling cost is given as a percentage of the inventory cost, the unit cost of the inventory is assumed to remain constant throughout the year.
- In case of cash discounts after ordering, the cost analysis of spare parts is assumed to be fixed without any fluctuation or special discounts.
- The quantity of spare parts ordered is considered to be delivered as one package at a time, and in case of travel problems due to different reasons, DSS does not take into account situations where the order is split into multiple shipments.
- By making these assumptions, the DSS can apply the EOQ to determine the optimal order quantities for each spare part.

The Economic Order Quantity (EOQ) is not primarily used for optimizing inventory levels, but rather for determining the order quantity that minimizes the total costs associated with inventory management. Some key costs related to inventory and maintenance management that can be to reduce inventory costs, improve inventory turnover, enhance efficiencies, and support better decision-making and interdepartmental satisfaction include:

Ordering costs include the administrative expenses, transportation, and receiving costs incurred with each order placement and processing.

Holding/carrying costs encompass the expenses of storing and maintaining inventory, such as warehouse expenses, insurance, taxes, obsolescence, and the opportunity cost of capital tied up.

Stockout costs are incurred when interdepartmental demand cannot be met due to insufficient inventory.

Setup and changeover costs are associated with the ordering process.

Data management costs involve maintaining accurate inventory records, tracking levels, and forecasting demand.

Labor costs cover the employees engaged in inventory management tasks like receiving, storing, and picking.

Therefore, the aim of this study is not to optimize inventory levels using the Economic Order Quantity (EOQ) , but rather to carefully analyze the various cost factors related to maintenance and inventory management in order to enable the case company to make better decisions.

- Reduce overall inventory and maintenance costs
- Improve inventory turnover and equipment utilization
- Enhance operational efficiencies and responsiveness
- Support better decision-making through data-driven insights
- Foster improved communication and collaboration between departments, such as purchasing, maintenances, and inventory.

4.5 Cost Analysis by Using Economic Order Quantity model

Since, the order spare parts are different items the average unit cost (i) must be need to analysisholding cost. from equation number, therefore: From Appendix B.

$$Average\ cost\ (i) = \frac{\sum each\ unit\ cost}{number\ of\ items}$$

= (3,377,007.13)/ 95

i = 35,547.44

Holding cost per unit item (C_C) = average unit cost $*$ percentage of carrying cost

=35,547.44*(81,429/447,683)/95

C_C = 68

From Appendix: B the item number (1) to calculate:

Annual holding cost (HE) $= 6/2 * CC$

= (6/2) *68

= 204.18

Annual setup cost item (CE) $= (D/Q) \ * \ C0$

= (6/6) *4,712.45

=4,712.45

Average inventory (I) $= \ Q/2$

=6/2

= 3 pics

Expected number of order (N) $= \ D/Q$

=250/1

=250 day

$$Inventory = \frac{annual\ demand}{avarage\ inventory}$$

=6/3

= 2 pics

Reorder point $(P_{OQ}) = $ demand per day(d) $*$ lead time new order(L)

Were, $Demand$ =0.024

d=1 pcs/day

$R_{op} = d * L$

$$per\ day(d) = \frac{demand}{number\ of\ working\ days}$$

To calculate the estimated lead time for a new order (L), considering the information provided in the "Estimating Lead Time Data" table, as well as the additional factors mentioned in the "General Challenges" section 3.7, the following approach can be taken:

The "Estimating Lead Time Data" table provides historical data on lead times for various spare parts. However, the company's specific conditions, such as ordering process ,foreign currency availability and global peace conditions, can impact the actual lead time. Additionally, the ordering process may not align with the company's scheduling, and most spare parts are not mass-produced items, which introduces complexities and constraints related to raw material availability, global peace related to raw material movement one please to another , and technological advancements.

Given these factors, a conservative approach is warranted. the company should consider a longer lead time to account for the potential challenges. Based on the information provided, a selected lead time of 8 weeks (a constant) would be a reasonable starting point.

To further refine the estimated lead time (L), the company should apply a coefficient (b) to the selected 8-week lead time to adjust for the specific conditions and challenges faced by the organization. A coefficient of condition 6 is suggested, considering the complexities and uncertainties involved in the spare parts procurement process.
we can proceed as follows:

Identify the relevant parameters from the "Estimating Lead Time Data" table 2, selected conditions 2 and 6 for this specific study.

Minimum lead time (a): This value represents the baseline lead time for the order.

Coefficient (b): This coefficient captures the degree to which lead time increases as demand rises, due to supply chain constraints

$\text{Lead time}(\text{L}) = \text{a} + \text{b} * \text{demand}$

From appendix B item number (1) current demand value is 6 unit

$L = a + b * demand$

=8 week +0.06*6

= (8*7) day+(0.06 days/unit*6unit)

=56.36days

=56days

therefor similar procedure follows other items

R_{Oq} = d * L

= 1pics/day *56 days

=56 pics

Therefore, total existing annual inventory cost=annual holding cost + annual set up cost

$$TIC_E = H_E + S_E \tag{28}$$

TIC_E =204.18 +4,712.45

=**4,916.0**

Safety stock = Z_{SCORE}*√lead time *variance

Where, Z_{SCORE} is 95% service level or confidential for availability spare parts that specificequipment types equal to 1.644856, Whereas demand variance are 2.24.

Therefore, safety stock for the first spare part item = 1.644856*√56 *2.24

=18 pics

Summarily other items Appendix: B done in detail.

Therefore, in this analysis, the order quantity for kit piston would be 6 pics, which:

- Aligns with the calculated Economic Order Quantity of 29 units, but insufficient safety stock of units to meet the desired 95% service level.

4.6 Cost Analysis of The Proposed Alternative Solution for order quantity

In this research, the proposal order quantity for kit piston item number (1) on appendix's C are:

$$\text{Propsed Order Quantity } (P_{OQ}) = \text{Ceiling } (\text{Max}(\text{EOQ}, \text{MOQ}), \text{MOQ})$$

Where, EOQ = 29 pics, MOQ (minimum order quantity) = 7

P_{OQ} = Ceiling (Max(EOQ, MOQ), MOQ)

=ceiling (Max (29,7),7)

= 35 pics

Safety stock proposed = Z_{SCORE}*√lead time *variance

Where, Z_{SCORE} is 95% service level or confidential for availability spare parts that specific equipment types equal to 8.2045, Whereas demand variance are 1.2816.

Therefore, safety stock for the first proposed item = 1.2818*√56 *8.2045

= 28 pics

Summarily other items Appendix: C done in detail.

Therefore, in this analysis, the proposed order quantity for kit piston would be 7pics, which

- Aligns with the calculated Economic Order Quantity of 29 units
- Provides a sufficient safety stock of units to meet the desired 90% service level

Therefore, total existing annual inventory cost=annual holding cost + annual set up cost

$$TIC_E = H_E + S_E \quad (28)$$

TIC_E =238 +4,038.

=**4,276.9**

Base on the above perspective and appendix B how to inventory level and ordering strategy using before proposed ordering quantity.

Back Loader spare part requirement befor proposed order quantity																					
It No	Description	Annual Request Quantity (D)	Current Demand	Available Balance	Order Quantity (Q)	Unit Price	Total Cost	Annual holding cost (H)	Annual Setup Cost (C)	N=D/Q	(T)	d	L	Rop	TIC	EOQ	Ss	var	Z score
1	Kit Piston	6	6	0	6	17593.49	105,560.94	204.00	4,712.0	1	250	1.00	56	56	4,916.00	29	18	2.24	1.64
2	Kit-Bearing	6	6	0	6	3062.21	18,373.26	204.00	4,712.0	1	250	1.00	56	56	4,916.00	29	18	2.24	1.64
3	Valve-Inlet	12	6	0	6	2572.42	15,434.52	204.00	9,424.0	2	125	2.00	56	113	9,628.00	41	18	2.24	1.64
4	Valve-Exhaust	12	6	0	6	2550.6	15,303.60	204.00	9,424.0	2	125	2.00	56	112	9,628.00	41	18	2.24	1.64
5	Kit-Bearing	2	1	0	1	6457.45	6,457.45	34.00	9,424.0	2	125	2.00	56	112	9,458.00	17	18	2.24	1.64
6	Gasket-Head	2	2	1	1	2170.48	4,340.96	34.00	9,424.0	2	125	2.00	56	112	9,458.00	17	18	2.24	1.64
7	Seal-Inlet V	1	1	0	1	4198.55	4,198.55	34.00	4,712.0	1	250	1.00	56	56	4,746.00	12	18	2.24	1.64
8	Insert-Valve	12	6	0	6	658.03	3,948.18	204.00	9,424.0	2	125	2.00	56	113	9,628.00	41	18	2.24	1.64
9	Guide-In Val Insert-Inlet	12	5	5	5	316.38	1,581.90	170.00	11,308.8	2	104	2.40	56	135	11,478.80	41	18	2.24	1.64
10	Bearing	2	1	0	1	2737.21	2,737.21	34.00	9,424.0	2	125	2.00	56	113	9,458.00	17	18	2.24	1.64
11	Shield-Heat	12	10	0	10	256.67	2,566.70	340.00	5,654.4	1	208	1.20	57	68	5,994.40	41	19	2.24	1.64
12	Seal-Exhaust Valve	12	7	2	5	276.19	1,933.33	170.00	11,308.8	2	104	2.40	56	-	11,478.80	41	18	2.20	1.64
							182,436.60	**1,836.00**							**100,788.00**				

From appendix B item number (1) back loader kit piston before proposed optimal ordering quantity list

Part Number 5081898

Annual Request Quantity 6pics

Current Demand 6pics

Available Balance Order Quantity (Q)................. 0

Order quantity… 6pics

Unit Price...17,593.49 birr

Total price ....105,560.96 birr

Annual Holding Cost(H)...204 birr

Annual Setup Cost(C) ....4,712 birr

Expected Number of Order (D/Q).......................... 1

Expected Time Between Order (T) ....250 days

Demand Per Day (D).. 1 pic

Reorder Point quantity (Roq) .... 56 pics

Total Exciting Annual Inventory Cost (Tic) ....4,916 birr

Economical Order Quantity (EOQ)..........................29 pics

Safety Stock...18 pics

Reorder quantity……………………………………..56 pics

Base on the above perspective and appendix C how to inventory level and ordering strategy proposed ordering quantity.

Back Loader spare part requirement befor proposed order quantity																				
It No	Description	Annual Request Quantity (D)	Current Demand	Available Balance	optimal Order Quantity (Q)	Unit Price	Total Cost	Annual holding cost (H)	Annual Setup Cost (C)	N=D/Q	(T)	d	L	Rop	TIC	EOQ	SS	Poq	Var	Z score
1	Kit Piston	6	6	10	7	17593.49	105,560.94	238.00	4,038.9	1.0	250	0.86	56	48	4,276.86	29	28	35	8.205	1.28155157
2	Kit-Bearing	6	6	0	9	3062.21	18,373.26	306.00	3,141.3	1.0	250	0.67	57	38	3,447.33	29	28	36	8.205	1.28155157
3	Valve-Inlet	12	6	0	6	2572.42	15,434.52	204.00	9,424.0	2.0	125	2.00	56	113	9,628.00	41	28	42	8.205	1.28155157
4	Valve-Exhaust	12	6	0	6	2550.6	15,303.60	204.00	9,424.0	2.0	125	2.00	56	113	9,628.00	41	28	42	8.205	1.28155157
5	Kit-Bearing	2	1	0	8	6457.45	6,457.45	272.00	1,178.0	1.0	250	0.25	56	14	1,450.00	17	22	24	8.205	1.036433
6	Gasket-Head	2	2	1	8	2170.48	4,340.96	272.00	1,178.0	1.0	250	0.25	56	14	1,450.00	17	22	24	8.205	1.036433
7	Seal-Inlet V	1	1	0	10	4198.55	4,198.55	340.00	471.2	1.0	250	0.10	57	6	811.20	12	18	20	8.205	0.841621
8	Insert-Valve	12	6	0	6	658.03	3,948.18	204.00	9,424.0	2.0	125	2.00	56	113	9,628.00	41	28	42	8.205	1.2816
9	Guide-In Val Insert-Inlet	12	5	5	6	316.38	1,581.90	204.00	9,424.0	2.0	125	2.00	56	113	9,628.00	41	28	42	8.205	1.2816
10	Bearing	2	1	0	8	2737.21	2,737.21	272.00	1,178.0	1.0	250	0.25	56	14	1,450.00	17	22	24	8.205	1.036433
11	Shield-Heat	12	10	0	10	256.67	2,566.70	340.00	5,654.4	1.2	208	1.20	57	68	5,994.40	41	28	50	8.205	1.2816
12	Seal-Exhaust Valve	12	7	2	7	276.19	1,933.33	238.00	8,077.7	1.7	146	1.71	56	97	8,315.71	41	28	42	8.205	1.2816
								3,094.00	**62,613.5**						**65,707.50**					

From appendix C item number (1) back loader kit piston after proposed optimal ordering quantity list

Part Number 5081898

Annual Request Quantity ....7 pics

Current Demand ....6 pics

Available Balance Order Quantity (Q)................. 0

Order quantity… 6pics

Unit Price..17,593.49 birr

Total price ....105,560.96 birr

Annual Holding Cost(H) ....238 birr

Annual Setup Cost(C) ....4,038.9 birr

Expected Number of Order (D/Q).......................... 1

Expected Time Between Order (T) ....250 days

Demand Per Day (D).. 1 pic

Reorder Point quantity (Roq) .... 48 pics

Total Exciting Annual Inventory Cost (Tic) ....4,276.86 birr

Economical Order Quantity (EOQ)..........................29 pics

Safety Stock..28 pics

Proposed order quantity…………………………………3pic

The comparative analysis showed after proposed that adjusting the reorder quantity impacted various parameters like annual setup cost, holding cost, reorder quantity, time between orders, inventory cost, and safety stock. By determining the optimal reorder quantity, the company was able to balance the economic order quantity (EOQ) with the safety stock requirements, avoiding the existing stockout problems. This alignment of EOQ and safety stock ensured more efficient and safer replenishment periods, minimizing stockouts and associated repair costs.

The proposed optimal reorder quantity changes reduced the annual inventory cost by improving the balance between setup, holding, and ordering costs. It also helped to lower repair costs by right-sizing the safety stock to better match actual demand variability and lead times, allowing quicker equipment repair and return to productivity.

In summary, the optimal reorder quantity determination achieved the right cost parameter balance, adjusted the EOQ to the appropriate safety stock to avoid stockout issues, and indirectly reduced repair costs associated with inventory and equipment failures, as the replenishment process became better synchronized with demand. This holistic inventory optimization approach, considering both cost factors and operational alignment, improved the company's overall supply chain efficiency and reduced maintenance-related expenses.

4.7 Discussions

The basic objective of this study is to reduce repair costs by formulating a decision proposal based on information from the maintenance and inventory management departments to achieve this, to implement an integrated management framework using a Decision Support System (DSS) and how support this develop decision support system for this company.

4.7.1 Developing a Decision Support System model

The key steps for developing a Decision Support System (DSS) for the case company:

Data Collection:

Collect comprehensive data on the company's inventory management and maintenance operations, including inventory levels, spare part demand, inventory costs, safety stock levels, reorder quantities, and maintenance-related inputs.

Inventory input				
	InPut	**Description**	**Current Data**	
1	Inventory Level	Available Balance on Stock	0	
2	Stockout Impact	Equipment Downtime Due to Stockout Impact	333 Hr	
3	Spare Part Demand Related To Failure	Current Demand Quantity	6 Pics	
4	Lead Time Planning	Estimating Lead Time Periods	56 Days	
5	Inventory Cost	Holding Cost	204 Birr	

		Ordering Cost	4,712 Birr	
6	Safety Stock	Critical Parts Quantity For Kit Piston	18 Pics	
7	Reorder Quantity	For Budgeting	56 Pics	
8	Inventory analysis techniques	- Reducing inventory cost, - improve inventory turnover, - enhanced efficiencies, - better decision making, - interdepartmental satisfaction.	EOQ	
		Maintenance input		
1	Failure `Mode	Risk Priority Number Value	Engine Component High RPN Compare To Other Failure	
2	Critical Component Prioritizing	Engine Component Part	Piston Ring, Connecting Rod,Valve Mechanize, Cylinder Head And Liner Wear	
3	Maintenance Cost	Incurring Cost For Maintenance Activity Related To Holding, Ordering , Total Purchased Cost And Overhead Cost	204+4712+105,560.9=110,476 Birr	
4	Equipment down statues	Most of equipment More than six down		

Data Analysis:

Conduct Failure Mode and Effects Analysis (FMEA) table to evaluate the impact of stockouts on maintenance activities and identify critical spare parts.

Model Development:

optimization models can be developed to optimize inventory levels and determine optimal reorder quantities. Incorporate optimization algorithms, including Economic Order Quantity (EOQ) optimization techniques table , to enhance inventory management strategies.

System Integration:

Integrate the predictive models and optimization algorithms into a comprehensive DSS framework that can provide existing -time alerts, suggestions, and recommendations. This integrate the DSS with the company's existing Enterprise Resource Planning (ERP), maintenance management, and procurement systems to ensure data accuracy and synchronization.

User Awareness:

Provide comprehensive awareness to the company's personnel on the DSS's features, functionalities, and decision-making processes. awarded users on data interpretation, model inputs, and the generation and implementation of recommendations to ensure effective utilization of the DSS.

How DSS (Decision Support System) can support a case company:

The DSS (Decision Support System) can support a case company predict Spare Part Demand in the following ways based on table 1 data company annual report stock out impact, table 4 FMEA analysis and appendix B,taking an example back loader critical engine component parts considering .

The current demand quantity for spare parts is item number (1) and (12) estimating lead time periods. The DSS can help forecast spare part demand based on historical data and lead time, and regression model analysis results enabling the company to plan its inventory accordingly.

Critical part engine component part list for back loader

Back Loader spare part requirement befor proposed order quantity																			
spare part type	Description	Annual Request Quantity (D)	Current Demand	Available Balance	Order Quantity (Q)	Unit Price	Total Cost	Annual holding cost (H)	Annual Setup Cost (C)	N=D/Q	(T)	d	Lead time(L)	Rop	TIC	EOQ	Ss	var	Z score
1	Kit Piston	6	6	0	6	17593.49	105,560.94	204.00	4,712.0	1	250	1.00	56	56	4,916.00	29	18	2.24	1.64
2	Kit-Bearing	6	6	0	6	3062.21	18,373.26	204.00	4,712.0	1	250	1.00	56	56	4,916.00	29	18	2.24	1.64
3	Valve-Inlet	12	6	0	6	2572.42	15,434.52	204.00	9,424.0	2	125	2.00	56	113	9,628.00	41	18	2.24	1.64
4	Valve-Exhaust	12	6	0	6	2550.6	15,303.60	204.00	9,424.0	2	125	2.00	56	112	9,628.00	41	18	2.24	1.64
5	Kit-Bearing	2	1	0	1	6457.45	6,457.45	34.00	9,424.0	2	125	2.00	56	112	9,458.00	17	18	2.24	1.64
6	Gasket-Head	2	2	1	1	2170.48	4,340.96	34.00	9,424.0	2	125	2.00	56	112	9,458.00	17	18	2.24	1.64
7	Seal-Inlet V	1	1	0	1	4198.55	4,198.55	34.00	4,712.0	1	250	1.00	56	56	4,746.00	12	18	2.24	1.64
8	Insert-Valve	12	6	0	6	658.03	3,948.18	204.00	9,424.0	2	125	2.00	56	113	9,628.00	41	18	2.24	1.64
9	Guide-In Val Insert-Inlet	12	5	5	5	316.38	1,581.90	170.00	11,308.8	2	104	2.40	56	135	11,478.80	41	18	2.24	1.64
10	Bearing	2	1	0	1	2737.21	2,737.21	34.00	9,424.0	2	125	2.00	56	113	9,458.00	17	18	2.24	1.64
11	Shield-Heat	12	10	0	10	256.67	2,566.70	340.00	5,654.4	1	208	1.20	57	68	5,994.40	41	19	2.24	1.64
12	Seal-Exhaust Valve	12	7	2	5	276.19	1,933.33	170.00	11,308.8	2	104	2.40	56	135	11,478.80	41	18	2.20	1.64
							182,436.60	**1,836.00**							**100,788.00**				

The advanced forecasting capabilities of the DSS, one of the technique regression modeling, enable the company to accurately predict spare parts demand, leading to better planning and inventory management. This enhanced demand forecasting directly contributes to cost reductions by avoiding stockouts and minimizing the need for expedited orders.

The regression model used to two variables, one is Annual request quantity(D) independent variable and lead time(L) dependent variables ,analysis using EXCEL.

Summary Output Multiple Regression Model for Annual Request Quantity (D) independent variables And Lead Time (L) dependent variables for back loader.

Regression Statistics	
Multiple R	0.84225506
R Square	0.709393586
Adjusted R Square	0.680332945
Standard Error	0.097168937
Observations	12

	df	SS	MS	F	Significance F
Regression	1	0.230482	0.230482	24.4108	0.000586536
Residual	10	0.094418	0.009442		
Total	11	0.3249			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	56.05874477	0.053702	1043.887	1.6E-26	55.9390894	56.1784001	55.93909	56.1784
Annual Request Quantity (D)	0.029835855	0.006039	4.94072	0.0005	0.016380669	0.04329104	0.016381	0.043291

Table 7: Interpretation Regression Analysis(Hinkle et al., 2003)

	R-squared Value	Interpretation
1	0.0 to 0.1	No linear relationship
2	0.1 to 0.3	Weak linear relationship
3	0.3 to 0.5	Moderate linear relationship
4	0.5 to 0.7	Strong linear relationship
5	0.7 to 1.0	Very strong linear relationship

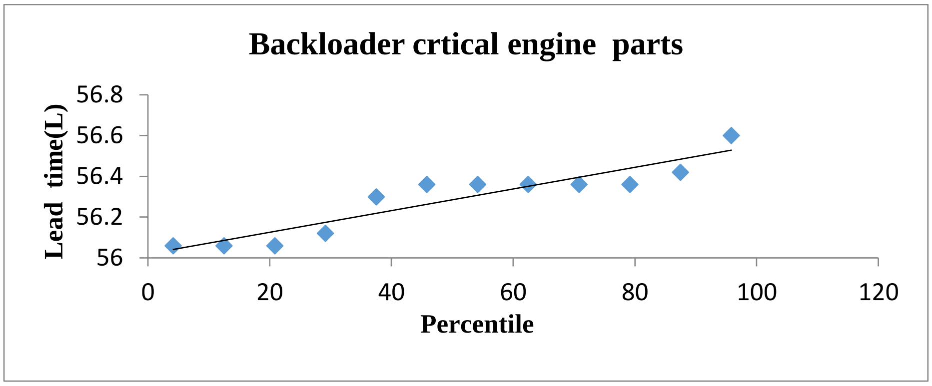
According to Hinkle et al. (2003), an R-squared value between 0.5 and 0.7 indicates a strong linear relationship between the predictor variable (annual request quantity) and the outcome variable (lead time). This means the regression model can explain a substantial portion of the variance in lead times and provides a good basis for making predictions about spare parts demand and lead times.

The R-squared value of 68.03% from the regression analysis falls into this 0.5 to 0.7 range, confirming the model has a strong predictive ability. This interpretation aligns with the guidelines from the original reference.

The most important figure in this context is the significance f value, f value < 0.05 the model is reliable, in this model the significant f value 0.000586 is well that threshold, so we can conclude that the entire model is relevant for our data.

Probability output table from regression model

Probability Output			
No	**Parts Name**	**Percentile (%)**	**Lead Time(L)**
1	Kit Piston	4.17	56
2	Kit-Bearing	12.50	56
3	Valve-Inlet	20.83	56
4	Valve-Exhaust	29.17	56
5	Kit-Bearing	37.50	56
6	Gasket-Head	45.83	56
7	Seal-Inlet V	54.17	56
8	Insert-Valve	62.50	56
9	Guide-In Val Insert-Inlet	70.83	56
10	Bearing	79.17	56
11	Shield-Heat	87.50	56
12	Seal-Exhaust Valve	95.83	57



Probability output table guide to how the company support this DSS system could use this information for ordering quantity prediction as follows:

Considering the "Kit Piston item number (1) back loader":

Percentage: 4.17%

Lead time (L): 56 days

The lowest percentile of 4.17% shows that "Kit piston" is the least likely to require replacement compared to the other 11 units. However, the 56 Lead time longer.

Based on regression model output, it suggests what kind of decision the organization should make.

Because the " kit piston" has a low predicted probability of failure, the company may not need to keep a large inventory of this parts on hand. However, the 56. A long lead time means that if a "kit piston " needs to be replaced, it will take a relatively long time to get a new one.

To mitigate this risk, the company needs to keep a small safety stock of "kit piston " parts on hand to cover lead time and any equipment maintenance delays pending replacements.

On the other hand, a percentile rating of 95.83 “Seal-Exhaust Valve “means that this part has the highest predicted probability of needing replacement among the item number (12) parts listed, and the lead time for this part is 56.6; Similarly,

Because the "Seal-Exhaust Valve" has such a high predicted probability of failure, it shows that the company needs to keep a large safety stock of these parts on hand;

A relatively long 56.6 means that it will take about 2 months to get a new part if needed. This can lead to stock out problems if not planned properly. the company needs to investigate ways to reduce lead time for this part, for example by identifying alternative suppliers, negotiating faster delivery, and helping it find a solution to the problem. The company also suggests that these "Seal-Exhaust Valves" should be monitored more closely before valve seal failure occurs.

From a risk management perspective, it helps the company develop contingency plans considering the potential impact of the failure of this high-probability.

By understanding the probability and lead time insights provided by the regression model, the company support this model by integrate the DSS with the company's existing Enterprise Resource Planning (ERP), maintenance management, and inventory management to ensure data accuracy and synchronization.

For inventory management, the company can adjust safety stock levels based on the predicted probability of part failure, and prioritize which parts to keep in inventory based on lead time requirements.

In inventory management, the company can identify parts with long lead times and take proactive measures to ensure timely delivery, as well as explore alternative solution to reduce lead times.

For maintenance planning, the company can incorporate the probability and lead time data into their maintenance schedules and maintenance plans, allowing them to anticipate potential maintenance delays or disruptions caused by long lead times for critical parts.

This allows the company to maximize their operational performance by having the right parts available when needed, minimize the risk of equipment downtime for long time, and optimize their overall supply chain and minimizing repair cost.

4.7.2 Model Verification and Validation

The following steps are followed to verify and validate the models in this thesis: Model verification begins with data preparation and cleaning. As described in Sections 3.3 and 4.2 of the study, in order to understand the current inventory management practices and to identify areas that need improvement, it tries to include information from stakeholders in the organization and what experiences they have, including various internal departments. Next, in the model develop phase, we implemented selected models and algorithms, such as regression analysis model and Failure Mode and Effects Analysis (FMEA), as mentioned in Section 4.3.

The model validation process begins with a comparative analysis, comparing the model results with existing company data to verify their accuracy and effectiveness. This may include comparing forecasted maintenance costs with actual costs, or inventory levels with actual stock levels.

From regression model analysis regression statistics the total variation in the lead time (dependent variable) data indicate reasonably good at predicting the lead time based on the part/component features, the significance f value, f value < 0.05 the model is reliable, in this model the significant f value 0.000586 is well that threshold, so we can conclude that the entire model is relevant for our data so the DSS model, and also the data extracted from regression output table;

Intercept:

The intercept value is 56.05874477, which represents the expected value of the dependent variable when all independent variables are equal to 0.

The standard error of the intercept is 0.053702, which is relatively small, indicating a precise estimation of the intercept.

The t-stat for the intercept is 1043.887, with an extremely low p-value (1.6E-26), well below the typical significance threshold of 0.05. This indicates the intercept is statistically significant.

The 95% confidence intervals for the intercept (55.93909 to 56.1784) do not include 0, further confirming the statistical significance of the intercept.

Annual Request Quantity (D):

The coefficient for the "Annual Request Quantity (D)" variable is 0.029835855, which means that for every one-unit increase in the independent variable, the dependent variable is expected to increase by 0.029835855 units, holding all other variables constant.

The standard error of the coefficient is 0.006039, which is relatively small, indicating a precise estimation of the coefficient.

The t-stat for the coefficient is 4.94072, with a p-value of 0.0005, which is well below the 0.05 significance level. This indicates the coefficient is statistically significant.

The 95% confidence intervals for the coefficient (0.016381 to 0.043291) do not include 0, further confirming the statistical significance of the coefficient.

Based on the information provided, the regression model appears to be valid and statistically significant. The low p-values for the intercept and the coefficient, as well as the 95% confidence intervals that do not include 0, suggest that the model is a good fit for the data and the independent variable is a significant predictor of the dependent variable.

4.7.3 The main contributions of this thesis for Sunshine Construction Company are:

Safety stock by accurately determining optimal inventory levels and lead times for spare parts. This involves using historical data, demand forecasting techniques,and advanced analytics to ensure critical parts availability while minimizing overall inventory costs.

Enhancing maintenance scheduling by combining maintenance history, and failure data, the thesis helps create a robust maintenance scheduling system that maximizes equipment uptime and reliability.

Improving Parts Management by implementing comprehensive parts tracking and tracing capabilities to proactively manage the spare parts inventory and reduce costly equipment downtime.

Developing a Decision Support System (DSS) using integration of maintenance requirements, inventory levels, and key decision variables. The DSS provides valuable insights and enables data-driven decision making to optimize inventory management and maintenance operations.

To utilize the key contributions of this thesis, Sunshine Construction Company should take the following steps:

Since the company's current data collection and documentation serves as a basis for analyzing the overall current situation and identifying areas for improvement, establishing proper documentation procedures for collecting and maintaining detailed historical data, maintenance history, equipment specifications, and failure patterns should be addressed and implemented appropriately.

Applying data-driven insights requires thorough analysis of collected data to gain valuable insights, and applying these insights to optimize inventory strategies and processes, such as, parts allocation, and demand forecasting.

Inventory analysis techniques such as the regression analysis and other advanced optimization techniques recommended in the analysis determine stock levels and replenishment rates for critical spare parts so that they have an understanding of the availability of time to reduce total inventory costs in various departments.

Developing and deploying a decision support system should create awareness that the development and deployment of an integrated DSS can help manage maintenance requirements, inventory levels, and other key decision variables with ease, and that DSS can provide valuable insights and inform decision-making to inventory management and maintenance activity.

Therefore, by following these steps, Sunshine Construction Company can effectively leverage the key contributions of the thesis to decision support its spare parts inventory management, enhance equipment reliability and availability, and ultimately improve its overall operational efficiency and profitability.

4.7.4 Theoretical implication

The thesis highlights several important theoretical contributions. The Decision Support System (DSS) enables existing -time data-driven insights to support informed decision-making for inventory management and reduce repair costs. The Economic Order Quantity (EOQ) just economic benefit better inventory control and planning by analyzing factors like holding costs and reorder points, leading to cost reductions. The reliable regression model can accurately forecast lead times, enabling better maintenance scheduling and planning. Incorporating probability and lead time data into overhaul and maintenance planning improves operations, minimizes downtime, and optimizes the supply chain.

CHAPTER FIVE

5.1 Conclusion

The study confirms that Sunshine Construction Company faces significant challenges in managing its spare parts inventory, including insufficient stock evaluations and ineffective stock management practices. Inaccurate demand forecasting and inconsistent supply chain processes are major contributors to these problems.

Due to the unavailability of spare parts within the required timeframe, more than 30 different equipment were kept out of service for over six months. Factors such as equipment variability, unpredictable demand patterns, and obsolescence risks further exacerbate the challenges. Inaccurate demand forecasting, insufficient visibility into inventory levels, and ineffective inventory control systems are additional factors affecting inventory management.

To address these challenges and facilitate improved spare parts inventory management, the study recommends several key directions for Sunshine Construction:

Develop a Decision Support System (DSS) that enables effective coordination between the maintenance and inventory departments. The DSS should incorporate techniques like economic order quantity, order point analysis, and demand forecasting to provide valuable insights and analysis to support informed decision-making.

Utilize both primary (observations, interviews) and secondary data sources (articles, journals, reports) as inputs to analyze historical data and exchange needs. Applying techniques such as regression analysis can lead to fundamental improvements in maintenance and spare parts management.

Enhance collaboration between the maintenance, warehouse, and procurement teams to improve communication and information sharing, leading to more efficient spare parts inventory management.

Prioritize the supply of critical components by assigning severity, occurrence, and detection levels to the major component failure modes, and calculating a Risk Priority Number (RPN) to identify the most critical components that require priority attention.

Implementing these strategies will enable Sunshine Construction to significantly improve its spare parts inventory management, reduce equipment downtime, lower maintenance costs, and ultimately result in more productive and streamlined operations.

5.2 Recommendation

The company has developed a Decision Support System (DSS) that integrates maintenance requirements, inventory levels, and key decision variables to provide insights and data-based decision making. This allows the organization to improve their maintenance operations and inventory management, leading to enhanced operational efficiency.

Applying modern inventory management technologies and the DSS serves as a strategic method to effectively connect maintenance and inventory management, enable data integration and collaborative decision-making, leading to cost savings, efficiency improvements, and improved organizational performance.

Considering the lead time of maintenance operations is critical to ensure timely procurement and shipment of spare parts. Facilitating decision-making processes helps to reduce equipment downtime and streamline maintenance operations.

By implementing these recommendations, Sunshine Construction Company can improve spare parts inventory management, reduce maintenance costs, and improve overall operational efficiency in the construction activity.

The key elements of the DSS that will optimize Sunshine Construction's inventory and maintenance operations include:

Maintenance Scheduling: Combining maintenance history, equipment specifications, and failure data to create a robust maintenance scheduling system that maximizes equipment uptime and reliability.

Parts Management: Providing comprehensive parts tracking and tracing capabilities to proactively manage the spare parts inventory and reduce costly equipment downtime.

To support the DSS implementation, Sunshine Construction will collect and maintain detailed historical data, apply these insights to optimize strategies and processes, and use models like regression model to manage the relationship spare parts for inventory levels. This comprehensive approach will help the company significantly reduce maintenance costs, improve equipment reliability and availability, and increase overall efficiency and profitability.

reference

Al-Turki, U., Duffuaa, S., & Bendaya, M. (2019). Trends in turnaround maintenance planning: literature review. *Journal of Quality in Maintenance Engineering*, *25*(2), 253-271.

Alahmadi, D. H., & Jamjoom, A. A. (2022). Decision support system for handling control decisions and decision-maker related to supply chain. *Journal of Big Data*, *9*(1), 114.

Ali, A., & Ratnayake, A. (2023). Demand Forecasting of Automobile Spare Parts after the End-of-Production-A review of demand forecasting models.

Antosz, K., & Ratnayake, R. C. (2019). Spare parts' criticality assessment and prioritization for enhancing manufacturing systems' availability and reliability. *Journal of Manufacturing Systems*, *50*, 212-225.

Atnafu, D., & Balda, A. (2018). The impact of inventory management practice on firms' competitiveness and organizational performance: Empirical evidence from micro and small enterprises in Ethiopia. *Cogent Business & Management*, *5*(1), 1503219.

Babaveisi, V., Teimoury, E., Gholamian, M. R., & Rostami-Tabar, B. (2023). Integrated demand forecasting and planning model for repairable spare part: an empirical investigation. *International Journal of Production Research*, *61*(20), 6791-6807.

Baker, A. R. P. C. P. (1994). Logistics and distribution management.

Boute, R. (2018). Forecasting spare part demand using service maintenance information. Twentieth International Working Seminar on Production Economics, Date: 2018/02/19-2018/02/23, Location: Innsbruck (Austria),

Boute, R. N., Gijsbrechts, J., Van Jaarsveld, W., & Vanvuchelen, N. (2022). Deep reinforcement learning for inventory control: A roadmap. *European Journal of Operational Research*, *298*(2), 401-412.

Chawla, G., & Miceli, V. (2019). Demand Forecasting and Inventory Management for Spare Parts.

Chong, A. K. W., Mohammed, A. H., Abdullah, M. N., & Rahman, M. S. A. (2019). Maintenance prioritization–a review on factors and methods. *Journal of Facilities Management*, *17*(1), 18-39.

Chopra, S., & Meindl, P. (2001). Strategy, planning, and operation. *Supply Chain Management*, *15*(5), 71-85.

Ciani, L., Guidi, G., & Patrizi, G. (2019). A critical comparison of alternative risk priority numbers in failure modes, effects, and criticality analysis. *Ieee Access*, *7*, 92398-92409.

Costantino, F., Di Gravio, G., Patriarca, R., & Petrella, L. (2018). Spare parts management for irregular demand items. *Omega*, *81*, 57-66.

De Jonge, B., & Scarf, P. A. (2020). A review on maintenance optimization. *European Journal of Operational Research*, *285*(3), 805-824.

Department, E. a. m. (2015). *sunshine construction equipment overhal activity annual report,addis ababa*.

Efrilianda, D. A., & Isnanto, R. R. (2018). Inventory control systems with safety stock and reorder point approach. 2018 International Conference on Information and Communications Technology (ICOIACT),

El Jaouhari, A., Alhilali, Z., Arif, J., Fellaki, S., Amejwal, M., & Azzouz, K. (2022). Demand forecasting application with regression and iot based inventory management system: a case study of a semiconductor manufacturing company. *International Journal of Engineering Research in Africa*, *60*, 189-210.

Er-Ratby, M., & Mabrouki, M. (2018). Critical Study of the Different Types of Maintenance Used in Industry. *Journal of Applied Sciences, Engineering and Technology*, *15*, 91-97.

Ermawanto, D., & Kurniati, N. (2021). Examining Inventory Management for Spare-Part Warehouse. 2nd South American Conference on Industrial Engineering and Operations Management, IEOM 2021,

Errandonea, I., Beltrán, S., & Arrizabalaga, S. (2020). Digital Twin for maintenance: A literature review. *Computers in Industry*, *123*, 103316.

Gallego-García, S., Gejo-García, J., & García-García, M. (2021). Development of a maintenance and spare parts distribution model for increasing aircraft efficiency. *Applied Sciences*, *11*(3), 1333.

Gonçalves, J. N., Carvalho, M. S., & Cortez, P. (2020). Operations research models and methods for safety stock determination: A review. *Operations Research Perspectives*, *7*, 100164.

Hinkle, D. E., Wiersma, W., & Jurs, S. G. (2003). *Applied statistics for the behavioral sciences* (Vol. 663). Houghton Mifflin Boston.

Hu, Q., Boylan, J. E., Chen, H., & Labib, A. (2018). OR in spare parts management: A review. *European Journal of Operational Research*, *266*(2), 395-414.

Jamaludin, M. F., & Bahaudin, M. F. (2022). Board Characteristics and Company Performance:

A Study of Shariah-Compliant Public Listed Companies in Malaysia. *Global Business and Management Research*, *14*(3s), 1559-1585.

Jenvald, M., & Hovmöller, M. (2020). Reducing Delays for Unplanned Maintenance of Service Parts in MRO Workshops: A case study at an aerospace and defence company. In.

Jonsson, P., & Mattsson, S.-A. (2019). An inherent differentiation and system level assessment approach to inventory management: A safety stock method comparison. *The International Journal of Logistics Management*, *30*(2), 663-680.

Kelly, B. D. (2021). Challenges to managing aging process equipment and infrastructure. *Process Safety Progress*, *40*(4), 266-271.

Khan, R. H., Sohrforouzani, M. A., Darvishi, S., & Ukwishaka, M. C. Big data analytics for optimizing supply chain management: a state of the art.

Kim, C. K., Kim, P., & Kwon, J. Y. (2022). Safety Stock Optimization under Lead Time Ambiguity. *Global Business & Finance Review*, *27*(5), 55.

Kulshrestha, N., Agrawal, S., & Shree, D. (2024). Spare parts management in industry 4.0 era: a literature review. *Journal of Quality in Maintenance Engineering*.

Ma, Z., Ren, Y., Xiang, X., & Turk, Z. (2020). Data-driven decision-making for equipment maintenance. *Automation in Construction*, *112*, 103103.

Manikandan, M., Adhiyaman, M., & Pazhani, K. (2018). A study and analysis of construction equipment management used in construction projects for improving productivity. *International Research Journal of Engineering and Technology*, *5*(3), 1297-1303.

Mashayekhy, Y., Babaei, A., Yuan, X.-M., & Xue, A. (2022). Impact of Internet of Things (IoT) on inventory management: A literature survey. *Logistics*, *6*(2), 33.

Masudin, I., Sumah, B., Zulfikarijah, F., & Restuputri, D. P. (2021). Effect of information technology on warehousing and inventory management for competitive advantage: a theoretical framework. In *Handbook of Research on Innovation and Development of E-Commerce and E-Business in ASEAN* (pp. 570-593). IGI Global.

Mazikana, A. T. (2023). The Impact of Inventory Management on the Overall Performance of the Organization. A Case of Halsted Builders Express. *A Case of Halsted Builders Express (March 16, 2023)*.

Mohsen, B. M. (2023). Developments of digital technologies related to supply chain management. *Procedia Computer Science*, *220*, 788-795.

Moradizadeh, S. (2019). *Economic Order Quantity (EOQ) Measurement Using Intelligent Systems Techniques*. The University of Regina (Canada).

MSHIU, G. (2021). *THE EFFECTIVENESS OF LEAD-TIME SUPPLIES ON PROCUREMENT PERFORMANCE IN TANZANIA* Institute of Accountancy Arusha (IAA)].

Muniz, L. R., Conceição, S. V., Rodrigues, L. F., de Freitas Almeida, J. F., & Affonso, T. B. (2021). Spare parts inventory management: a new hybrid approach. *The International Journal of Logistics Management*, *32*(1), 40-67.

Munyaka, J.-C. B., & Yadavalli, S. V. (2022). Inventory Management Concepts and Implementations: A Systematic Review. *South African Journal of Industrial Engineering*, *32*(2). https://doi.org/10.7166/33-2-2527

Nchekwube, D. C., Ferracuti, F., Freddi, A., Iarlori, S., Longhi, S., & Monteriù, A. (2022). Predictive Maintenance of Industrial Equipment using Deep Learning: from sensory data to remaining useful life estimation. 2022 IEEE International Conference on Metrology for Extended Reality, Artificial Intelligence and Neural Engineering (MetroXRAINE),

Pawar, N., & Tiple, B. (2019). Demand Forecasting of Anti-Aircraft Missile Spare Parts Using Neural Network. 2019 3rd International conference on Electronics, Communication and Aerospace Technology (ICECA),

Perez, H. D., Hubbs, C. D., Li, C., & Grossmann, I. E. (2021). Algorithmic approaches to inventory management optimization. *Processes*, *9*(1), 102.

Rahimi-Ghahroodi, S., Al Hanbali, A., Vliegen, I., & Cohen, M. A. (2019). Joint optimization of spare parts inventory and service engineers staffing with full backlogging. *International journal of production economics*, *212*, 39-50.

Ramezani, S., & Hoseinzadeh, M. R. (2022). MRO Spare Parts Management and Inventory Optimization. In *Cases on Optimizing the Asset Management Process* (pp. 266-301). IGI Global.

Ramos, E., Pettit, T. J., Flanigan, M., Romero, L., & Huayta, K. (2020). Inventory management model based on lean supply chain to increase the service level in a distributor of automotive sector. *Int. J. Supply Chain Manag*, *9*(2), 113-131.

Rubel, K. (2021). Increasing the Efficiency and Effectiveness of Inventory Management by Optimizing Supply Chain through Enterprise Resource Planning Technology. *EFFLATOUNIA-Multidisciplinary Journal*, *5*(2), 1739-1756.

Shrestha, L. (2021). Multiperspective Assessment of Enterprise Data Storage Systems Using Hierarchical Decision Modeling: The Case of Artificial Intelligence Workload for Information Technology Operations. (ProQuest Dissertation & Theses)

Silvestri, L., Forcina, A., Introna, V., Santolamazza, A., & Cesarotti, V. (2020). Maintenance transformation through Industry 4.0 technologies: A systematic literature review. *Computers in Industry*, *123*, 103335.

Siponen, M., Haapasalo, H., & Harkonen, J. (2019). Maintenance, repair, and operations inventory reduction and operational development. *International Journal of Industrial and Systems Engineering*, *32*(1), 1-31.

Tahir, N., & Choudhary, M. A. (2011). Development of a decision support system for Inventory Analysis and Control. First International Technology Management Conference,

Teerasoponpong, S., & Sopadang, A. (2022). Decision support system for adaptive sourcing and inventory management in small-and medium-sized enterprises. *Robotics and Computer-Integrated Manufacturing*, *73*, 102226.

Thomas, D. S., & Thomas, D. S. (2018). *The costs and benefits of advanced maintenance in manufacturing*. US Department of Commerce, National Institute of Standards and Technology ….

Tien, N. H., Anh, D. B. H., & Thuc, T. D. (2019). Global supply chain and logistics management. In: Academic Publications, Dehli.

Tiwari, S. (2021). Supply chain integration and Industry 4.0: a systematic literature review. *Benchmarking: An International Journal*, *28*(3), 990-1030.

Vicil, O. (2021). Optimizing stock levels for service-differentiated demand classes with inventory rationing and demand lead times. *Flexible Services and Manufacturing Journal*, *33*(2), 381-424.

Yavuz, A. (2023). Spare part classification and inventory control improvement for case company.

Yip, H.-l., Fan, H., & Chiang, Y.-h. (2014). Predicting the maintenance cost of construction equipment: Comparison between general regression neural network and Box–Jenkins time series models. *Automation in Construction*, *38*, 30-38.

Yusuf, A., & Soediantono, D. (2022). Supply chain management and recommendations for implementation in the defense industry: a literature review. *International Journal of*

Social and Management Studies, *3*(3), 63-77.

Zhang, S., Huang, K., & Yuan, Y. (2021). Spare Parts Inventory Management: A Literature Review. Sustainability 2021, 13, 2460. In: s Note: MDPI stays neutral with regard to jurisdictional claims in published ….

Appendix:

Appendix: A

SCHOOL OF GRADUATE STUDIES OF ADDIS ABABA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR DEGREE OF MASTERS OF SCIENCE IN MECHANICAL AND INDUSTRIAL ENGINEERING (INDUSTRIAL ENGINEERING STREAM)

Dear:

I am a graduate student at Addis Ababa University, specializing in mechanical and industrial engineering, focusing on industrial engineering. I am currently researching for my master's degree, and would like your valuable input and expertise for a research project titled 'Decision Support System Development for Spare Parts Inventory Management: Sunshine Construction Company'. The purpose of this study is to reduce maintenance costs and improve the efficiency of spare parts management processes in Sunshine Construction. As a key stakeholder in the company's spare parts management, your insights and experiences are critical to the success of this project.

If you are available, please let us know your preferred date, time, and method of communication for the questionnaires. We are committed to working around your schedule.

You can rest assured that your involvement is entirely voluntary and that the survey guarantees complete anonymity. The data you provide will be handled with utmost confidentiality and will solely be utilized for academic objectives. Your participation in this study will help improve the performance of Sunshine Construction's inventory management system.

Thank you in for your cooperation and contribution to this research. If you require any further or necessitate additional details, kindly do not hesitate to reach out to me at 0913034934.

I look forward to your positive response and the opportunity to collaborate on this important initiative

Regarding!

Biruk G\Medhine

Section-Questionnaires

Personal information:

Current position ………………………………

Qualification…………………………………..

Service year……………………………………….

Gender ………………………………………….

Potential Failure Made and Effect Analysis			safety hazarded (1-10)	reduced performance (1-10)	overall system functionality (1-10)	visual inspection (1-10)	auditor inspection (1-10)	performance monitoring (1-10)	sensor monitoring (1-10)	Diagnostics system (1-10)	predictive maintenance (1-10)
	Item/ Function	Potential Failure Mode									
1	engine	Piston ring wear or breakage									
		Connecting rod wear or failure									
		Crankshaft and bearing wear or failure									
		Oil burning or leakage									
		Valve mechanism wear or failure									
		Coolant leaks									
		Cylinder head cracking or gasket failure									
		Cylinder liner and block wear or cracking									
		Incomplete combustion issues									
2	transmission	Inadequate lubrication or oil supply									
		Harsh or abnormal shifting techniques									

		Wear or failure of gears, bearings, shafts, and synchronizing parts									
		Wear or failure of friction plates and discs									
		Seal wear or failure									
		Overload or excessive operating conditions									
3	hydraulics	Worn or leaking seals									
		Worn or damaged hoses									
		Wear or failure of internal hydraulic components									
		Contaminated or insufficient hydraulic oil									
		Hydraulic oil cooling system issues									
		Air entrainment in the hydraulic system									
4	brake	Wear and deterioration of brake system components									
		Wear or failure of brake discs and friction plates, pad lining, shoe									
		Inadequate maintenance and servicing									
		Vacuum seal leaks in the brake booster system									
5	power train	Wear or failure of internal and external parts:									
		Seals, shafts, bearings friction disc, pressure plate									
		Discs, plates									
		Hoses, pipes, fittings									
		Hydraulic system issues:									
		motor, Pump, control valve, or actuator failure									
		Internal component wear or breakage									
		Differential wear or failure									
		Excessive load or operating conditions									
		Operator/driver inexperience or poor technique									
6	undercarriage	Wear of track shoes, sprockets, and idlers									
		Excessive loads and operating in severe environments									
		Delayed replacement of worn components									
		Improper adjustments and maintenance									
		Hydraulic system issues:									
		Leaks in hoses and fittings									
		Wear or damage to cylinder shafts and rods									
7	suspension	Wear and deterioration of internal and external suspension components:									
		Bushings, seals									
		Weak or damaged springs									
		Improper tire inflation pressure									
		Use of incorrect tire size									
		Operation in harsh working conditions									
		Delayed replacement of worn parts									
		Lack of regular, proper maintenance									

8	electrical	Electrical system issues:									
		Sensor or control component failure due to wear,calibration issues, or damage									
		Wiring and connection problems, including corrosion and vibration damage									
		Wear or failure of electrical components likebearings, bushings, and fans									
		Improper installation, adjustment, or wear of components like V-belts									
		Delayed replacement of worn or damaged parts									
		Charging system malfunction									

It. No	Guide Line	Activity
1	visual inspection	wear, leaks, damage
2	auditor inspection	abnormal noise, knocking or grinding
3	performance monitoring	tracking parameters like pressure, temperature, speed
4	sensor monitoring	measured and analysis specific parameter
5	Diagnostics system	data analysis techniques to interpreted sensor data
6	predictive maintenance	historical data recording, proactive

Appendix: B: how to optimized inventory level and ordering strategy using sensitivity analysis before optimal proposed ordering quantity.

Back Loader																				
It No	**Description**	**Part Number**	**Annual Request Quantity (D)**	**Current Demand**	**Available Balance**	**Order Quantity (Q)**	**Unit Price**	**Total Cost**	**Annual holding cost (H)**	**Annual Setup Cost (C)**	**N=D/Q**	**(T)**	**d**	**L**	**Rop**	**TIC**	**EOQ**	**Ss**	var	Z score
1	Kit Piston	5081898	6	6	0	6	17593.49	105,560.94	204.00	4,712.0	1	250	1.00	56	56	4,916.00	29	18	2.24	1.64
2	Kit-Bearing	2255499	6	6	0	6	3062.21	18,373.26	204.00	4,712.0	1	250	1.00	56	56	4,916.00	29	18	2.24	1.64
3	Valve-Inlet	2543954	12	6	0	6	2572.42	15,434.52	204.00	9,424.0	2	125	2.00	56	113	9,628.00	41	18	2.24	1.64
4	Valve-Exhaust	2255495	12	6	0	6	2550.6	15,303.60	204.00	9,424.0	2	125	2.00	56	112	9,628.00	41	18	2.24	1.64
5	Kit-Bearing	5185437	2	1	0	1	6457.45	6,457.45	34.00	9,424.0	2	125	2.00	56	112	9,458.00	17	18	2.24	1.64
6	Gasket-Head	3229663	2	2	1	1	2170.48	4,340.96	34.00	9,424.0	2	125	2.00	56	112	9,458.00	17	18	2.24	1.64
7	Seal-Inlet V	2584946	1	1	0	1	4198.55	4,198.55	34.00	4,712.0	1	250	1.00	56	56	4,746.00	12	18	2.24	1.64
8	Insert-Valve	3296655	12	6	0	6	658.03	3,948.18	204.00	9,424.0	2	125	2.00	56	113	9,628.00	41	18	2.24	1.64
9	Guide-In Val Insert-Inlet	1850882	12	5	5	5	316.38	1,581.90	170.00	11,308.8	2	104	2.40	56	135	11,478.80	41	18	2.24	1.64
10	Bearing	3668853	2	1	0	1	2737.21	2,737.21	34.00	9,424.0	2	125	2.00	56	113	9,458.00	17	18	2.24	1.64
11	Shield-Heat	2370769	12	10	0	10	256.67	2,566.70	340.00	5,654.4	1	208	1.20	57	68	5,994.40	41	19	2.24	1.64
12	Seal-Exhaust Valve	2526438	12	7	2	5	276.19	1,933.33	170.00	11,308.8	2	104	2.40	56	1,621	11,478.80	41	18	2.20	1.64
			91	**57**	**8**	**54**	**42849.68**	**182,436.60**	**1,836.00**	**98,952.0**	**21**	**1,917**	**21.00**	**675**	**2,667**	**100,788.00**	**364**	**222**		
Dozer																				
13	Piston Crown,	1684540	36	12	6	6	11819.91	141,838.92	204.00	28,272.0	6	42	0.14	57	6	28,476.00	71	147	140.23	1.64
14	Valve Lifter	1291351	36	24	0	24	5626.01	135,024.24	816.00	7,068.0	2	167	0.14	57	24	7,884.00	71	148	140.23	1.64
15	Piston Ring	1723284	36	12	0	12	5938.95	71,267.40	408.00	14,136.0	3	83	0.14	57	12	14,544.00	71	147	140.23	1.64
16	Sleeve	1948124	36	36	2	34	1681.26	60,525.36	1,156.00	4,989.2	1	236	0.14	58	34	6,145.18	71	149	140.23	1.64
17	Liner, Cylinder-Bore Rplc 2	1979322	36	24	18	6	2210.1	53,042.40	204.00	28,272.0	6	42	0.14	57	6	28,476.00	71	148	140.23	1.64
18	Piston Ring, Intermediate	1644187	36	30	0	30	814.22	24,426.60	1,020.00	5,654.4	1	208	0.14	58	30	6,674.40	71	148	140.23	1.64
19	Piston Ring, Top	1343761	36	30	8	22	592	17,760.00	748.00	7,710.5	2	153	0.14	58	22	8,458.55	71	148	140.23	1.64
20	Fuel Filter	Ff5319	75	5	1	4	2609.74	13,048.70	136.00	88,350.0	19	13	0.30	56	4	88,486.00	102	146	140.23	1.64
21	Fuel Separator	Fs20007	75	5	0	5	2583.9	12,919.50	170.00	70,680.0	15	17	0.30	56	5	70,850.00	102	146	140.23	1.64
22	Fuel Separator	Fs20051	75	5	0	5	2239.38	11,196.90	170.00	70,680.0	15	17	0.30	56	5	70,850.00	102	146	140.23	1.64
			477	**183**	**35**	**148**	**36115.47**	**541,050.02**	**5,032.00**	**325,812.1**	**69**	**977**	**1.91**	**571**	**148**	**330,844.12**	**800**	**1,472**		

								Excavator												
23	Fuel Pump	Km-6745-71-117	1	1	0	1	153481.36	153,481.36	34.00	4,712.0	1	250	0.00	56	0	4,746.00	12	182	217.56	1.64
24	Injector	Km-6745-12-310	12	6	3	3	20044.75	120,268.50	102.00	18,848.0	4	63	0.05	56	3	18,950.00	41	182	217.56	1.64
25	Turbocharger	Km-6745-81-804	2	1	0	2	35096.83	35,096.83	68.00	4,712.0	1	250	0.01	56	0	4,780.00	17	182	217.56	1.64
26	Piston Kit	Km-6745-32-212	12	6	0	6	5480.16	32,880.96	204.00	9,424.0	2	125	0.05	56	3	9,628.00	41	182	217.56	1.64
27	Ring Kit	Km-6745-31-201	24	12	0	12	1873.04	22,476.48	408.00	9,424.0	2	125	0.10	57	5	9,832.00	58	183	217.56	1.64
28	Exhaust Valve	Km-6745-41-415	48	24	0	24	840.63	20,175.12	816.00	9,424.0	2	125	0.19	57	11	10,240.00	82	184	217.56	1.64
29	Liner Kit	Km-6742-01-515	12	6	0	6	2811.28	16,867.68	204.00	9,424.0	2	125	0.05	56	3	9,628.00	41	182	217.56	1.64
30	Intake Valve	Km-6745-41-416	48	24	0	24	666.65	15,999.60	816.00	9,424.0	2	125	0.19	57	11	10,240.00	82	184	217.56	1.64
31	Guide	Km-6745-49-413	48	48	3	45	285.95	13,725.60	1,530.00	5,026.1	1	234	0.19	59	11	6,556.13	82	186	217.56	1.64
32	Ring	Km-6745-31-115	2	1	0	1	9670.1	9,670.10	34.00	9,424.0	2	125	0.01	56	0	9,458.00	17	182	217.56	1.64
33	Sensor	Km-6741-81-922	4	1	0	1	4163.52	4,163.52	34.00	18,848.0	4	63	0.02	56	1	18,882.00	24	182	217.56	1.64
			213	**130**	**6**	**125**	**234414.27**	**444,805.75**	**4,250.00**	**108,690.1**	**23**	**1,609**	**0.85**	**624**	**49**	**112,940.13**	**493**	**2,010**		
								Toyota												
34	Valve Exhaust	F T13715-30040	3	24	5	19	432.4	10,377.60	646.00	744.0	1.00	250	1.00	57	250	1,390.00	20	129	108.00	1.64
35	Piston Sun-Assy	F T13101-30081-0	2	6	8	2	443.05	2,658.30	68.00	4,712.0	1.00	250	1.00	56	250	4,780.00	17	128	108.00	1.64
36	Valve Intake	T+B3:L3813711-30	3	24	18	6	2402.95	57,670.80	204.00	2,356.0	1.00	250	1.00	56	250	2,560.00	20	128	108.00	1.64
			8	**54**	**31**	**27**	**3278.4**	**70,706.70**	**918.00**	**7,812.0**	3.00	**750**	**3.00**	170	**750**	**8,730.00**	**57**	**386**		
								Loader												
37	Injector	*Vl-204506	6	6	3	3	37800.73	226,804.38	102.00	9,424.0	2	125	0.02	56	3	9,526.00	29	22	3.19	1.64
38	Ecu	*Vl-111844	1	1	0	1	152260.61	152,260.61	34.00	4,712.0	1	250	0.00	56	1	4,746.00	12	22	3.19	1.64
39	Ecu	*Vl-601000	1	1	0	1	116066.49	116,066.49	34.00	4,712.0	1	250	0.00	56	1	4,746.00	12	22	3.19	1.64
40	Ecu	*Vl-601000	1	1	0	1	116066.49	116,066.49	34.00	4,712.0	1	250	0.00	56	1	4,746.00	12	22	3.19	1.64
41	Turbocharger	*Vl-214966	1	1	0	1	47283.65	47,283.65	34.00	4,712.0	1	250	0.00	56	1	4,746.00	12	22	3.19	1.64
42	Solenoid Val	*Vl-117096	3	3	0	3	12919.5	38,758.50	102.00	4,712.0	1	250	0.01	56	3	4,814.00	20	22	3.19	1.64
43	Nozzle	*Vl-205726	6	6	0	6	6218.01	37,308.06	204.00	4,712.0	1	250	0.02	56	6	4,916.00	29	22	3.19	1.64
44	Fuel Regulate	*Vl-216386	2	2	0	2	16716.68	33,433.36	68.00	4,712.0	1	250	0.01	56	2	4,780.00	17	22	3.19	1.64
45	Fuel Pump	*Vl-210214	1	1	0	1	11488.02	11,488.02	34.00	4,712.0	1	250	0.00	56	1	4,746.00	12	22	3.19	1.64
46	Pressure Sen	*Vl-110395	1	2	0	2	5976.27	11,952.54	68.00	2,356.0	1	250	0.00	56	1	2,424.00	12	22	3.19	1.64
47	Sensor	*Vl-204506	2	2	0	2	3821.88	7,643.76	68.00	4,712.0	1	250	0.01	56	2	4,780.00	17	22	3.19	1.64
48	Pressure	*Vl-111700	2	2	0	2	3732.3	7,464.60	68.00	4,712.0	1	250	0.01	56	2	4,780.00	17	22	3.19	1.64
49	Pressure Sen	*Vl-110395	1	1	0	1	4209.46	4,209.46	34.00	4,712.0	1	250	0.00	56	1	4,746.00	12	22	3.19	1.64
			28	**29**	**3**	**26**	**534560.09**	**810,739.92**	**884.00**	**63,612.0**	**14**	**3,125**	**0.11**	730	**25**	**64,496.00**	**210**	**286**		

								Grader												
50	Liner Cylinder	4695314	12	6	0	6	11711.96	70,271.76	204.00	9,424.0	2	125	0.05	56	6	9,628.00	41	130	110.58	1.64
51	Piston	2382710	24	12	0	12	4462.11	53,545.32	408.00	9,424.0	2	125	0.10	57	12	9,832.00	58	130	110.58	1.64
52	Lifter	2511005	6	6	5	1	6921.98	41,531.88	34.00	28,272.0	6	42	0.02	56	1	28,306.00	29	130	110.58	1.64
53	Tube Ass Oil	2741587	6	6	0	6	6336.87	38,021.22	204.00	4,712.0	1	250	0.02	56	6	4,916.00	29	130	110.58	1.64
54	Rod Assy	1556629	4	2	1	1	37053.13	74,106.26	34.00	18,848.0	4	63	0.02	56	1	18,882.00	24	130	110.58	1.64
55	Piston Ring	610497	2	1	0	1	32172.43	32,172.43	34.00	9,424.0	2	125	0.01	56	1	9,458.00	17	130	110.58	1.64
56	Body As	1646560	24	12	8	4	2507.53	30,090.36	136.00	28,272.0	6	42	0.10	57	4	28,408.00	58	130	110.58	1.64
57	Ring Oil	4p1659	24	12	0	12	2485.14	29,821.68	408.00	9,424.0	2	125	0.10	57	12	9,832.00	58	130	110.58	1.64
58	Lifter Assy	2027475	8	4	3	1	6887.53	27,550.12	34.00	37,696.0	8	31	0.03	56	1	37,730.00	33	130	110.58	1.64
59	Lifter	2165383	10	5	0	5	4968.55	24,842.75	170.00	9,424.0	2	125	0.04	56	5	9,594.00	37	130	110.58	1.64
60	Shiel Oil	6n7174	32	16	9	7	1288.5	20,616.00	238.00	21,540.6	5	55	0.13	57	7	21,778.57	67	131	110.58	1.64
61	Insert	1799453	24	12	6	6	1633.02	19,596.24	204.00	18,848.0	4	63	0.10	57	6	19,052.00	58	130	110.58	1.64
62	Piston Ring	1687212	24	12	6	6	2485.14	29,821.68	204.00	18,848.0	4	63	0.10	57	6	19,052.00	58	130	110.58	1.64
63	Arm Valve	1159398	4	2	0	2	7261.33	14,522.66	68.00	9,424.0	2	125	0.02	56	2	9,492.00	24	130	110.58	1.64
64	Ring	9s3029	24	12	6	6	2331.83	27,981.96	204.00	18,848.0	4	63	0.10	57	6	19,052.00	58	130	110.58	1.64
65	Valve Inlet	7e9578	24	12	10	2	3589.32	43,071.84	68.00	56,544.0	12	21	0.10	57	2	56,612.00	58	130	110.58	1.64
66	Valve Exhaust	1337029	24	12	10	2	3578.41	42,940.92	68.00	56,544.0	12	21	0.10	57	2	56,612.00	58	130	110.58	1.64
67	Liner Cylinder	3715941	12	48	6	42	366.91	17,611.68	1,428.00	1,346.3	1	250	0.05	59	12	2,774.29	41	133	110.58	1.64
68	Guide	1008150	48	24	22	2	963.51	23,124.24	68.00	113,088.0	24	10	0.19	57	2	113,156.00	82	131	110.58	1.64
			336	216	92	124	139005.2	661,241.00	4,216.00	479,950.9		1,721	1.34		94	484,166.86	883	2,474		
			336	**216**	**92**	**124**	**139005.2**	**661,241.00**	**4,216.00**	**479,950.9**	**103**	**1,721**	**1.34**	**1,077**	**94**	**484,166.86**	**883**	**2,474**		
								Sandvick Drill												
69	Injector Gp	20r-9079	1	1	0	1	98,310.50	98,310.50	34.00	4,712.0	1	250	0.00	56	1	4,746.00	12	22.49	3.33	1.64
70	Deutz Fuel Inject. Pump	Bf 4m1013ec	6	6	0	6	26,149.64	156,897.84	204.00	4,712.0	1	250	0.02	56	6	4,916.00	29	22.55	3.33	1.64
71	Deutz Fuel Injector	Bf 4m1013ec	6	6	0	6	22,704.44	136,226.64	204.00	4,712.0	1	250	0.02	56	6	4,916.00	29	22.55	3.33	1.64
72	Valve Assembly	55065591	1	1	0	1	73,177.77	73,177.77	34.00	4,712.0	1	250	0.00	56	1	4,746.00	12	22.49	3.33	1.64
73	Air Filter Kit	55152254	6	3	0	3	9,883.70	29,651.10	102.00	9,424.0	2	125	0.02	56	3	9,526.00	29	22.51	3.33	1.64
74	Air Valve	55204759/ 55007801	5	2	0	2	12,990.13	25,980.26	68.00	11,780.0	3	100	0.02	56	2	11,848.00	26	22.50	3.33	1.64
75	Air Filter Kit	55152253	5	3	0	3	7,078.74	21,236.22	102.00	7,853.3	2	150	0.02	56	3	7,955.33	26	22.51	3.33	1.64
76	Valve	80759069	4	4	0	4	4,179.60	16,718.40	136.00	4,712.0	1	250	0.02	56	4	4,848.00	24	22.52	3.33	1.64
77	Filter Element	55089267	9	2	0	2	6,532.67	13,065.34	68.00	21,204.0	5	56	0.04	56	2	21,272.00	35	22.50	3.33	1.64
78	Filter Element	55089266	9	2	0	2	3,878.15	7,756.30	68.00	21,204.0	5	56	0.04	56	2	21,272.00	35	22.50	3.33	1.64
			52	30	0	30	264,885.34	579,020.37	1,020.00	95,025.3	20	1,736	0.21	58	30	96,045.33	257	225		
			52	**30**	**0**	**30**	**264,885.34**	**579,020.37**	**1,020.00**	**95,025.3**	**20**	**1,736**	**0.21**	**620**	**30**	**96,045.33**	**257**	**225**		
								Dump Trucks												
79	Turbo Charger	1420196606	1	1	0	1	268438.5	268,438.50	34.00	4,712.0	1	250	0.00	56	1	4,746.00	12	67	30.00	1.64
80	Valve Intake	1320196009	12	24	12	12	14986.62	359,678.88	408.00	4,712.0	2	125	0.05	57	6	5,120.00	41	68	30.00	1.64
81	Valve Exhaust	13202nc000	12	24	0	24	14986.62	359,678.88	816.00	2,356.0	1	250	0.05	57	12	3,172.00	41	68	30.00	1.64
82	Liner Kit	1100096727	16	4	0	4	75105.36	300,421.44	136.00	18,848.0	4	63	0.06	56	4	18,984.00	47	68	30.00	1.64
83	Nozzle	1662096573	12	24	0	24	10967.22	263,213.28	816.00	2,356.0	1	250	0.05	57	12	3,172.00	41	68	30.00	1.64
84	Metal Set Shell /Std/	1221396526	24	6	0	6	29571.3	177,427.80	204.00	18,848.0	4	63	0.10	56	6	19,052.00	58	68	30.00	1.64
85	Bearing (Fr Inner)	4021700z0d	32	8	0	8	18833.76	150,670.08	272.00	18,848.0	4	63	0.13	56	8	19,120.00	67	68	30.00	1.64
86	Timer Automatic	16851nb006	1	1	0	1	127644.66	127,644.66	34.00	4,712.0	1	250	0.00	56	1	4,746.00	12	67	30.00	1.64
87	Guide Valve Intake	1321296011	12	24	20	4	3961.98	95,087.52	136.00	14,136.0	3	83	0.05	57	4	14,272.00	41	68	30.00	1.64
88	Guide Valve Exhaust	1321196009	12	24	0	24	1492.92	35,830.08	816.00	2,356.0	1	250	0.05	57	12	3,172.00	41	68	30.00	1.64
89	Con Rod Metal /Std/	1211796576	24	6	0	6	2411.64	14,469.84	204.00	18,848.0	4	63	0.10	56	6	19,052.00	58	68	30.00	1.64
90	Washer Set Trust	1228097225	24	6	2	4	3158.1	18,948.60	136.00	28,272.0	6	42	0.10	56	4	28,408.00	58	68	30.00	1.64
91	Engine Control System	5222423434	4	1	0	1	829317.06	829,317.06	34.00	18,848.0	4	63	0.02	56	1	18,882.00	24	67	30.00	1.64
92	Engine Brake Sense	5221991154	6	3	0	3	175131	525,393.00	102.00	9,424.0	2	125	0.02	56	3	9,526.00	29	68	30.00	1.64
93	Control Unit	478509z00a	4	1	0	1	314259.66	314,259.66	34.00	18,848.0	4	63	0.02	56	1	18,882.00	24	67	30.00	1.64
94	Control Unit	259459z00b	1	1	0	1	131147.28	131,147.28	34.00	4,712.0	1	250	0.00	56	1	4,746.00	12	67	30.00	1.64
95	IECU	5224066740	1	1	0	1	100485	100,485.00	34.00	4,712.0	1	250	0.00	56	1	4,746.00	12	67	30.00	1.64
			198	**159**	**34**	**125**	**2,121,898.68**	**4,072,111.56**	**4,250.00**	**195,548.0**	**44**	**2,500**	**0.79**	**66**	**83**	**199,798.00**	**614**	**1,152**		
			1403	**858**	**209**	**659**	**3,377,007.13**	**7,362,111.92**												

Appendix C: how to optimized inventory level and ordering strategy using sensitivity analysis after optimal proposed ordering quantity.

										Back Loader											
It No	**Description**	**Part Number**	**Annual Request Quantity (D)**	**Current Demand**	**Available Balance**	**optimal Order Quantity (Q)**	**Unit Price**	**Total Cost**	**Annual holding cost (H)**	**Annual Setup Cost (C)**	**N=D/Q**	**(T)**	**d**	**L**	**Rop**	**TIC**	**EOQ**	**SS**	**Poq**	Var	Z score
1	Kit Piston	5081898	6	6	10	7	17593.49	105,560.94	238.00	4,038.9	1.0	250	0.86	56	48	4,276.86	29	28	35	8.205	1.2816
2	Kit-Bearing	2255499	6	6	0	9	3062.21	18,373.26	306.00	3,141.3	1.0	250	0.67	57	38	3,447.33	29	28	36	8.205	1.2816
3	Valve-Inlet	2543954	12	6	0	6	2572.42	15,434.52	204.00	9,424.0	2.0	125	2.00	56	113	9,628.00	41	28	42	8.205	1.2816
4	Valve-Exhaust	2255495	12	6	0	6	2550.6	15,303.60	204.00	9,424.0	2.0	125	2.00	56	113	9,628.00	41	28	42	8.205	1.2816
5	Kit-Bearing	5185437	2	1	0	8	6457.45	6,457.45	272.00	1,178.0	1.0	250	0.25	56	14	1,450.00	17	22	24	8.205	1.036
6	Gasket-Head	3229663	2	2	1	8	2170.48	4,340.96	272.00	1,178.0	1.0	250	0.25	56	14	1,450.00	17	22	24	8.205	1.036
7	Seal-Inlet V	2584946	1	1	0	10	4198.55	4,198.55	340.00	471.2	1.0	250	0.10	57	6	811.20	12	18	20	8.205	0.842
8	Insert-Valve	3296655	12	6	0	6	658.03	3,948.18	204.00	9,424.0	2.0	125	2.00	56	113	9,628.00	41	28	42	8.205	1.2816
9	Guide-in Val Insert-Inlet	1850882	12	5	5	6	316.38	1,581.90	204.00	9,424.0	2.0	125	2.00	56	113	9,628.00	41	28	42	8.205	1.2816
10	Bearing	3668853	2	1	0	8	2737.21	2,737.21	272.00	1,178.0	1.0	250	0.25	56	14	1,450.00	17	22	24	8.205	1.036
11	Shield-Heat	2370769	12	10	0	10	256.67	2,566.70	340.00	5,654.4	1.2	208	1.20	57	68	5,994.40	41	28	50	8.205	1.2816
12	Seal-Exhaust Valve	2526438	12	7	2	7	276.19	1,933.33	238.00	8,077.7	1.7	146	1.71	56	97	8,315.71	41	28	42	8.205	1.2816
			91	**4.75**	**18**	**91**	**42849.68**	**182,436.60**	**3,094.00**	**62,613.5**	**16.9**	**2,354**	**13.29**	**56**		**65,707.50**	**364**	**28**	**423**		
Dozer																					
13	Piston Crown,	1684540	36	12	6	7	11819.91	141,838.92	238.00	24,233.1	5.1	49	1.00	57	57	24,471.14	71	75	77	140.23	0.8416
14	Valve Lifter	1291351	36	24	0	30	5626.01	135,024.24	1,020.00	5,654.4	1.2	208	1.00	57	57	6,674.40	71	76	90	140.23	0.8416
15	Piston Ring	1723284	36	12	0	30	5938.95	71,267.40	1,020.00	5,654.4	1.2	208	1.00	57	57	6,674.40	71	75	90	140.23	0.8416
16	Sleeve	1948124	36	36	2	34	1681.26	60,525.36	1,156.00	4,989.2	1.1	236	1.00	58	58	6,145.18	71	76	102	140.23	0.8416
17	Liner, Cylinder-Bore R	1979322	36	24	18	14	2210.1	53,042.40	476.00	12,116.6	2.6	97	1.00	57	57	12,592.57	71	76	84	140.23	0.8416
18	Piston Ring, Intermedia	1644187	36	30	0	30	814.22	24,426.60	1,020.00	5,654.4	1.2	208	1.00	58	58	6,674.40	71	76	90	140.23	0.8416
19	Piston Ring, Top	1343761	36	30	8	22	592	17,760.00	748.00	7,710.5	1.6	153	1.00	58	58	8,458.55	71	76	88	140.23	0.8416
20	Fuel Filter	Ff5319	54	5	1	4	2609.74	13,048.70	136.00	63,612.0	13.5	19	1.00	56	56	63,748.00	87	75	88	140.23	0.8416
21	Fuel Separator	Fs20007	54	5	0	5	2583.9	12,919.50	170.00	50,889.6	10.8	23	1.00	56	56	51,059.60	87	75	90	140.23	0.8416
22	Fuel Separator	Fs20051	54	5	0	5	2239.38	11,196.90	170.00	50,889.6	10.8	23	1.00	56	56	51,059.60	87	75	90	140.23	0.8416
			414	**18.3**	**35**	**181**	**36115.47**	**541,050.02**	**6,154.00**	**231,403.8**	**49.1**	**1,225**	**10.00**	**57**	**571**	**237,557.84**	**754**	**75**			

Excavator																					
23	Fuel Pump	Km-6745-71-117	1	1	0	1	153481.36	153,481.36	34.00	4,712.0	1.0	250	1.00	56	250	4,746.00	12	10	12	217.56	0.6745
24	Injector	Km-6745-12-310	12	6	3	3	20044.75	120,268.50	102.00	18,848.0	4.0	63	1.00	56	56	18,950.00	41	33	42	217.56	1.2816
25	Turbocharger	Km-6745-81-804	2	1	0	2	35096.83	35,096.83	68.00	4,712.0	1.0	250	1.00	56	56	4,780.00	17	14	18	217.56	0.6745
26	Piston Kit	Km-6745-32-212	12	6	0	7	5480.16	32,880.96	238.00	8,077.7	1.7	146	1.00	56	56	8,315.71	41	33	42	217.56	0.8416
27	Ring Kit	Km-6745-31-201	24	12	0	12	1873.04	22,476.48	408.00	9,424.0	2.0	125	1.00	57	57	9,832.00	58	43	60	217.56	0.8416
28	Exhaust Valve	Km-6745-41-415	48	24	0	24	840.63	20,175.12	816.00	9,424.0	2.0	125	1.00	57	57	10,240.00	82	61	96	217.56	0.8416
29	Liner Kit	Km-6742-01-515	12	6	0	6	2811.28	16,867.68	204.00	9,424.0	2.0	125	1.00	56	56	9,628.00	41	30	42	217.56	0.8416
30	Intake Valve	Km-6745-41-416	48	24	6	30	666.65	15,999.60	1,020.00	7,539.2	1.6	156	1.00	57	57	8,559.20	82	68	90	217.56	0.8416
31	Guide	Km-6745-49-413	48	48	3	45	285.95	13,725.60	1,530.00	5,026.1	1.1	234	1.00	59	59	6,556.13	82	83	90	217.56	0.8416
32	Ring	Km-6745-31-115	2	1	0	1	9670.1	9,670.10	34.00	9,424.0	2.0	125	1.00	56	56	9,458.00	17	12	17	217.56	0.8416
33	Sensor	Km-6741-81-922	4	1	0	1	4163.52	4,163.52	34.00	18,848.0	4.0	63	0.02	56	1	18,882.00	24	12	24	217.56	0.8416
			213	**130**	**12**	**132**	**234414.27**	**444,805.75**	**4,488.00**	**105,459.0**	**22.4**	**1,661**	**10.02**	**624**	**763**	**109,947.05**	**493**				
Toyota																					
34	Valve Exhaust	F T13715-300	3	12	5	19	432.4	5,188.80	646.00	744.0	1.0	250	1.00	57	250	1,390.00	20	34	38	12.00	1.2816
35	Piston Sun-Assy	F T13101-300	2	6	8	15	443.05	2,658.30	510.00	628.3	1.0	250	1.00	57	250	1,138.27	17	14	30		0.5244
36	Valve Intake	T+B3:L38137	3	12	18	15	2402.95	28,835.40	510.00	942.4	1.0	250	1.00	57	250	1,452.40	20	27	30		1.0364
			8	**30**	**31**	**49**	**3278.4**	**36,682.50**	**1,666.00**	**2,314.7**	3.0	**750**	**3.00**	171	**750**	**3,980.67**	**57**				
Loader																					
37	Injector	*Vl-204506	6	6	3	3	37800.73	226,804.38	102.00	9,424.0	2.0	125	0.02	56	3	9,526.00	29	22	30	3.19	1.6449
38	Ecu	*Vl-111844	1	1	0	1	152260.61	152,260.61	34.00	4,712.0	1.0	250	0.00	56	1	4,746.00	12	11	12	3.19	0.8416
39	Ecu	*Vl-601000	1	1	0	1	116066.49	116,066.49	34.00	4,712.0	1.0	250	0.00	56	1	4,746.00	12	11	12	3.19	0.8416
40	Ecu	*Vl-601000	1	1	0	1	116066.49	116,066.49	34.00	4,712.0	1.0	250	0.00	56	1	4,746.00	12	11	12	3.19	0.8416
41	Turbocharger	*Vl-214966	1	1	0	1	47283.65	47,283.65	34.00	4,712.0	1.0	250	0.00	56	1	4,746.00	12	11	12	3.19	0.8416
42	Solenoid Val	*Vl-117096	3	3	0	3	12919.5	38,758.50	102.00	4,712.0	1.0	250	0.01	56	3	4,814.00	20	22	21	3.19	0.8416
43	Nozzle	*Vl-205726	6	6	0	6	6218.01	37,308.06	204.00	4,712.0	1.0	250	0.02	56	6	4,916.00	29	22	30	3.19	0.8416
44	Fuel Regulate	*Vl-216386	2	2	0	2	16716.68	33,433.36	68.00	4,712.0	1.0	250	0.01	56	2	4,780.00	17	9	18	3.19	0.6745
45	Fuel Pump	*Vl-210214	1	1	0	1	11488.02	11,488.02	34.00	4,712.0	1.0	250	0.00	56	1	4,746.00	12	14	12	3.19	1.0364
46	Pressure Sen	*Vl-110395	1	2	0	3	5976.27	11,952.54	102.00	1,570.7	1.0	250	0.00	56	1	1,672.67	12	14	12	3.19	1.0364
47	Sensor	*Vl-204506	2	2	0	2	3821.88	7,643.76	68.00	4,712.0	1.0	250	0.01	56	2	4,780.00	17	14	18	3.19	1.0364
48	Pressure	*Vl-111700	2	2	0	2	3732.3	7,464.60	68.00	4,712.0	1.0	250	0.01	56	2	4,780.00	17	14	18	3.19	1.0364
49	Pressure Sen	*Vl-110395	1	1	0	3	4209.46	4,209.46	102.00	1,570.7	0.3	750	0.00	56	3	1,672.67	12	11	12	3.19	0.8416
			28	**29**	**3**	**29**	**534560.09**	**810,739.92**	**986.00**	**59,685.3**	**13.3**	**3,625**	**0.11**	730	**27**	**60,671.33**	**210**				

									Grader												
50	Liner Cylinder	4695314	12	6	0	10	11711.96	70,271.76	340.00	5,654.4	1.2	208	0.05	56	10	5,994.40	41	44	50	2,198.5	0.1257
51	Piston	2382710	24	12	0	12	4462.11	53,545.32	408.00	9,424.0	2.0	125	0.10	57	12	9,832.00	58	44	60	2,198.5	0.1257
52	Lifter	2511005	6	6	5	9	6921.98	41,531.88	306.00	3,141.3	0.7	375	0.02	56	9	3,447.33	29	26	36	2,198.5	0.0753
53	Tube Ass Oil	2741587	6	6	0	6	6336.87	38,021.22	204.00	4,712.0	1.0	250	0.02	56	6	4,916.00	29	26	30	2,198.5	0.0753
54	Rod Assy	1556629	4	2	1	6	37053.13	74,106.26	204.00	3,141.3	0.7	375	0.02	56	6	3,345.33	24	26	24	2,198.5	0.0753
55	Piston Ring	610497	2	1	0	4	32172.43	32,172.43	136.00	2,356.0	0.5	500	0.01	56	4	2,492.00	17	18	20	2,198.5	0.0502
56	Body As	1646560	24	12	8	4	2507.53	30,090.36	136.00	28,272.0	6.0	42	0.10	57	4	28,408.00	58	44	60	2,198.5	0.1257
57	Ring Oil	4p1659	24	12	0	12	2485.14	29,821.68	408.00	9,424.0	2.0	125	0.10	57	12	9,832.00	58	44	60	2,198.5	0.1257
58	Lifter Assy	2027475	8	4	3	4	6887.53	27,550.12	136.00	9,424.0	2.0	125	0.03	56	4	9,560.00	33	26	36	2,198.5	0.0753
59	Lifter	2165383	10	5	0	5	4968.55	24,842.75	170.00	9,424.0	2.0	125	0.04	56	5	9,594.00	37	26	40	2,198.5	0.0753
60	Shiel Oil	6n7174	32	16	9	7	1288.5	20,616.00	238.00	21,540.6	4.6	55	0.13	57	7	21,778.57	67	44	70	2,198.5	0.1257
61	Insert	1799453	24	12	6	6	1633.02	19,596.24	204.00	18,848.0	4.0	63	0.10	57	6	19,052.00	58	44	60	2,198.5	0.1257
62	Piston Ring	1687212	24	12	6	6	2485.14	29,821.68	204.00	18,848.0	4.0	63	0.10	57	6	19,052.00	58	44	60	2,198.5	0.1257
63	Arm Valve	1159398	4	2	0	2	7261.33	14,522.66	68.00	9,424.0	2.0	125	0.02	56	2	9,492.00	24	18	24	2,198.5	0.0502
64	Ring	9s3029	24	12	6	6	2331.83	27,981.96	204.00	18,848.0	4.0	63	0.10	57	6	19,052.00	58	44	60	2,198.5	0.1257
65	Valve Inlet	7e9578	24	12	10	2	3589.32	43,071.84	68.00	56,544.0	12.0	21	0.10	57	2	56,612.00	58	44	58	2,198.5	0.1257
66	Valve Exhaust	1337029	24	12	10	2	3578.41	42,940.92	68.00	56,544.0	12.0	21	0.10	57	2	56,612.00	58	44	58	2,198.5	0.1257
67	Liner Cylinder	3715941	12	48	6	42	366.91	17,611.68	1,428.00	1,346.3	1.0	250	0.05	59	12	2,774.29	41	36	42	2,198.5	0.1004
68	Guide	1008150	48	24	22	3	963.51	23,124.24	102.00	75,392.0	16.0	16	0.19	57	3	75,494.00	82	45	84	2,198.5	0.1004
			336	**216**	**92**	**148**	**139005.2**	**661,241.00**	**5,032.00**	**362,307.9**		**2,924**	**1.34**		**118**	**367,339.92**	**883**	-			
									Sandvick Drill												
69	Injector Gp	20r-9079	1	1	0	1	98,310.50	98,310.50	34.00	4,712.0	1.0	250	0.00	56	1	4,746.00	12	9	12	3.333	0.6745
70	Deutz Fuel Inject. Pump	Bf 4m1013ec	6	6	0	6	26,149.64	156,897.84	204.00	4,712.0	1.0	250	0.02	56	6	4,916.00	29	23	30	3.333	1.6449
71	Deutz Fuel Injector	Bf 4m1013ec	6	6	0	6	22,704.44	136,226.64	204.00	4,712.0	1.0	250	0.02	56	6	4,916.00	29	23	30	3.333	1.6449
72	Valve Assembly	55065591	1	1	0	5	73,177.77	73,177.77	170.00	942.4	0.2	1,250	0.00	56	5	1,112.40	12	14	15	3.333	1.0364
73	Air Filter Kit	55152254	6	3	0	3	9,883.70	29,651.10	102.00	9,424.0	2.0	125	0.02	56	3	9,526.00	29	23	30	3.333	1.6449
74	Air Valve	55204759/ 55007801	5	2	0	2	12,990.13	25,980.26	68.00	11,780.0	2.5	100	0.02	56	2	11,848.00	26	22	28	3.333	1.6449
75	Air Filter Kit	55152253	5	3	0	3	7,078.74	21,236.22	102.00	7,853.3	1.7	150	0.02	56	3	7,955.33	26	23	27	3.333	1.6449
76	Valve	80759069	4	4	0	4	4,179.60	16,718.40	136.00	4,712.0	1.0	250	0.02	56	4	4,848.00	24	23	24	3.333	1.6449
77	Filter Element	55089267	9	2	0	2	6,532.67	13,065.34	68.00	21,204.0	4.5	56	0.04	56	2	21,272.00	35	22	36	3.333	1.6449
78	Filter Element	55089266	9	2	0	2	3,878.15	7,756.30	68.00	21,204.0	4.5	56	0.04	56	2	21,272.00	35	22	36	3.333	1.6449
			52	30	0	34	264,885.34	579,020.37	1,156.00	91,255.7	19.4	2,736	0.21	58	34	92,411.73	257				
			52	**30**	**0**	**34**	**264,885.34**	**579,020.37**	**1,156.00**	**91,255.7**	**19.4**	**2,736**	**0.21**	**620**	**34**	**92,411.73**	**257**				
									Dump Trucks												
79	Turbo Charger	1420196606	1	1	0	1	268438.5	268,438.50	34.00	4,712.0	1.0	250	0.00	56	1	4,746.00	12	11	12	98.154	0.1510
80	Valve Intake	1320196009	12	24	12	24	14986.62	359,678.88	816.00	2,356.0	2.0	125	0.05	57	6	3,172.00	41	35	48	98.154	0.4677
81	Valve Exhaust	13202nc000	12	24	0	24	14986.62	359,678.88	816.00	2,356.0	1.0	250	0.05	57	12	3,172.00	41	35	48	98.154	0.4677
82	Liner Kit	1100096727	16	12	0	24	75105.36	901,264.32	816.00	3,141.3	0.7	375	0.06	57	24	3,957.33	47	50	48	98.154	0.6745
83	Nozzle	1662096573	12	24	0	19	10967.22	263,213.28	646.00	2,976.0	1.0	250	0.05	57	12	3,622.00	41	35	57	98.154	0.4677
84	Metal Set Shell /Std/	1221396526	24	6	0	12	29571.3	177,427.80	408.00	9,424.0	2.0	125	0.10	56	12	9,832.00	58	35	60	98.154	0.4677
85	Bearing (Fr Inner)	4021700z0d	32	8	0	12	18833.76	150,670.08	408.00	12,565.3	2.7	94	0.13	56	12	12,973.33	67	35	72	98.154	0.4677
86	Timer Automatic	16851nb006	1	1	0	2	127644.66	127,644.66	68.00	2,356.0	0.5	500	0.00	56	2	2,424.00	12	9	12	98.154	0.1257
87	Guide Valve Intake	1321296011	12	24	20	4	3961.98	95,087.52	136.00	14,136.0	3.0	83	0.05	57	4	14,272.00	41	35	44	98.154	0.4677
88	Guide Valve Exhaust	1321196009	12	24	0	24	1492.92	35,830.08	816.00	2,356.0	1.0	250	0.05	57	12	3,172.00	41	35	48	98.154	0.4677
89	Con Rod Metal /Std/	1211796576	24	6	0	12	2411.64	14,469.84	408.00	9,424.0	2.0	125	0.10	56	12	9,832.00	58	35	60	98.154	0.4677
90	Washer Set Trust	1228097225	24	6	2	4	3158.1	18,948.60	136.00	28,272.0	6.0	42	0.10	56	4	28,408.00	58	35	60	98.154	0.4677
91	Engine Control System	5222423434	4	1	0	1	829317.06	829,317.06	34.00	18,848.0	4.0	63	0.02	56	1	18,882.00	24	15	24	98.154	0.2019
92	Engine Brake Sense	5221991154	6	3	0	3	175131	525,393.00	102.00	9,424.0	2.0	125	0.02	56	3	9,526.00	29	15	30	98.154	0.4677
93	Control Unit	478509z00a	4	1	0	1	314259.66	314,259.66	34.00	18,848.0	4.0	63	0.02	56	1	18,882.00	24	15	24	98.154	0.4677
94	Control Unit	259459z00b	1	1	0	1	131147.28	131,147.28	34.00	4,712.0	1.0	250	0.00	56	1	4,746.00	12	9	12	98.154	0.1257
95	IECU	5224066740	1	1	0	1	100485	100,485.00	34.00	4,712.0	1.0	250	0.00	56	1	4,746.00	12	9	12	98.154	0.1257
			198	**167**	**34**	**169**	**2,121,898.68**	**4,672,954.44**	**5,746.00**	**150,618.7**	**34.8**	**3,219**	**0.79**	**66**	**120**	**156,364.67**	**614**				
			1340	**625.05**	**225**	**833**	**3,377,007.13**	**7,928,930.60**													